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DESCRIPTION AND CORRELATION OF THE ROMNEY FORMATION OF MARYLAND.[1]

CONDENSED DESCRIPTION OF THE ROMNEY FORMATION.

THE lower member of the Romney formation in Allegany county is composed principally of fissile black shale, some of which weathers to a yellowish or buff color on long exposure. In comparatively fresh exposures, however, as in the railroad cuts at Twenty-first Bridge, the shales are either black or rusty-brown after some weathering. The black shales are shown to best advantage in these cuts, although on the Williams Road, three and one-half miles southeast of Cumberland, is perhaps the most nearly complete exposure of this division with an approximate thickness of 512 feet. In the lower part of some of these exposures are bands of very dark-colored thin limestone. The lithological characters of these shales agree closely with those of typical exposures of the Marcellus shales in New York state, and in addition they contain such characteristic species as *Liorhynchus limitare* (Vanuxem) and *Agonitaites expansus* (Vanuxem).

The second member of the Romney formation, the Hamilton beds, has an approximate thickness of 1,100 feet, and is composed of shales and sandstones. In recent exposures the shales, generally bluish or bluish-gray in color, vary in composition from quite coarse arenaceous to those that are fine and argillaceous. The sandstones,

[1] Published by permission of Dr. William Bullock Clark, state geologist of Maryland. The data upon which this paper is based will appear in detail in the forthcoming Devonian volume of the Maryland Geological Survey.

which on fresh surface are generally blue or gray in color, are not very coarse in texture, and the layers are often less than a foot thick. All of these rocks, however, on long exposure usually present along the highways a slightly greenish or yellowish-gray tint. There are two prominent sandstone zones in this member of the formation, varying in thickness from about 30 to 75 feet. The lower one is from 500 to 550 feet above the base of this division, or from 1,000 to 1,050 feet above the base of the formation, while the upper zone is at or near the top of the formation. Both of these sandstone zones are clearly shown in the sections on the Williams Road and at Great Cacapon, and the upper one at Gilpin and above Corriganville. The shales in many localities are very fossiliferous, especially those between the two sandstone zones, and contain numerous specimens of such characteristic species of the New York Hamilton as *Spirifer mucronatus* (Conrad), *S. granulosus* (Conrad), *Athyris spiriferoides* (Eaton), *Tropidoleptus carinatus* (Conrad), *Chonetes coronatus* (Conrad), *Phacops rana* (Green), and other species. On account of the presence of numerous Hamilton species together with a lithologic similarity and approximate stratigraphic position, this division of the Romney formation is regarded as equivalent to the Hamilton stage of New York.

The estimates of the thickness of the Romney formation vary from about 1,600 to 1,650 feet. In Allegany county both the Marcellus shale and Hamilton stage are clearly shown; but farther east in Washington county the Marcellus shale or a part of it is wanting. This would indicate that the subsidence of the Onondaga land area began at an earlier date in Allegany than in Washington county.

CORRELATION OF THE MARCELLUS SHALE.

The lithological similarity of the thin, black shales forming the lower part of the Romney formation to the Marcellus shale of New York has been noted in the description of the Romney formation, and in other places in the Maryland volume. This is so marked in connection with its similar stratigraphic position that the northward continuation of these shales in Bedford county, Pennsylvania, were unhesitatingly called the Marcellus by Professor Stevenson in his geological report of that county. Following the northeasterly

strike of the Devonian formations across Pennsylvania, a similar lithologic and stratigraphic shale has been noted by various geologists at different localities, until Monroe county in the northeastern part of the state is reached, where it was positively identified by Dr. I. C. White. The localities in the northeastern part of the state were later studied by the writer, who from the lithologic, stratigraphic, and paleontologic evidence fully accepted Dr. White's correlation.[1] This practically carried the black shale into southeastern New York, where the identification of the black, fissile shale below the Hamilton beds as the Marcellus has not been questioned. Finally, in the Cumberland basin of Maryland Mr. Schuchert positively identifies this shale as "the Marcellus stage of the Middle Devonic," which he states "rests directly upon the eroded Oriskanian."[2]

These shales in general are sparingly fossiliferous in Maryland and northern West Virginia; but there are occasional layers in some localities which contain a more abundant fauna. There may be a question whether the fossiliferous zones noted at certain localities are not stratigraphically above the very fissile bituminous shale so well exposed in the southern part of the Baltimore & Ohio Railroad cut at Twenty-first Bridge, which agrees so strikingly with the Marcellus shale of New York. The writer has studied to some extent the fauna found mainly in the shales which lithologically closely agree with the New York Marcellus. Dr. J. M. Clarke has probably a larger collection, obtained in part from the fossiliferous layers mentioned above, which he is elaborating, and consequently this is to be regarded as only a preliminary account of this fauna.

Twenty-one species have been listed by the writer from these shales, three of which are restricted to Maryland.[3] The other eighteen either occur in New York or are represented by closely affiliated species. These species range in New York from the Schoharie grit to the Chemung, inclusive, and the formations containing the largest number of them, which therefore become the most important in correlation, are as follows: Marcellus, 10 identical, 4 affiliated;

[1] *Bulletin No. 120* (1894), U. S. Geological Survey, p. 4.

[2] *Proceedings of the U. S. National Museum*, Vol. XXVI (1903), p. 422.

[3] Tables giving the geological range and geographical distribution of the Romney species will be published in the Maryland Devonian volume.

Hamilton, 8 identical, 6 affiliated; Sherburne, 2 identical, 3 affiliated; Ithaca, 8 identical, 3 affiliated; and the Chemung, with 3 identical, and 2 affiliated. It will thus be seen that, so far as this fauna is concerned, it indicates the correlation of this shale with the Marcellus shale and Hamilton beds of New York, with the evidence somewhat in favor of the Marcellus, since it contains 10 identical species to 8 in the Hamilton. The weight of evidence in favor of correlation with the Marcellus shale is strengthened when the list is examined a little more closely. *Liorhynchus limitare* (Vanuxem), which, so far as I am aware, is confined to the Marcellus shale in New York, and perhaps may be considered its most characteristic fossil, or at least its most distinctive Brachiopod, is found generally in the black, fissile shale constituting the lower part of the Romney formation in Maryland. *Bactrites aciculatus* (Hall) is known only in the Marcellus of New York, and the *Agoniatites expansus* (Vanuxem) is so characteristic of a thin layer of limestone in the lower Marcellus of New York that it has been named the Agoniatite limestone. In Maryland 170 feet or more above the base of the black shales are thin limestones which also contain *Agoniatites expansus* (Vanuxem).

Finally, it may be said that, so far as the paleontological evidence is concerned, it shows a close relationship between the Maryland black shales and the Hamilton beds of New York, and Dr. John M. Clarke has already shown that such a relation exists in New York, since a large percentage of the species found in the Marcellus shale of that state occurs in its Hamilton beds.[1] The paleontological evidence, however, shows a still closer relationship with the Marcellus shale fauna of New York, which is supported by the visible continuity, lithologic similarity,[2] and stratigraphic position of the containing shales, so that the correlation of this Maryland black shale with the Marcellus shale of New York appears to be fairly well sustained.

CORRELATION OF THE HAMILTON BEDS.

The rocks overlying the Marcellus shale of the Romney formation, and extending northeasterly from northern West Virginia across

[1] *Eighth Annual Report of State Geologist of New York*, 1889, pp. 60, 61.

[2] For a summary of the various methods of correlation see MR. GILBERT in *Compte rendu*, Fifth Session, International Geological Congress, 1893, pp. 151–54.

Maryland and Pennsylvania to New York, have been much more frequently correlated with the Hamilton beds of New York. Professor James Hall and other paleontologists have identified collections of fossils from these rocks in northern West Virginia, and from intermediate localities between that state and New York, as composed of Hamilton species. If the various geological maps, reports, and papers describing the Devonian formations from West Virginia to New York are put together and considered, it will be found that this correlation is strongly supported by visible continuity. Furthermore, the stratigraphic position of these beds strongly supports this correlation.

The paleontological data are as yet much more extensive regarding the Hamilton beds than for the Marcellus shale. The total number of species recorded by the writer from the Hamilton beds of Maryland is 147, of which 21 are limited to Maryland, leaving 126 identical or closely related species which also occur in New York. An enumeration of the totals for the New York Devonian formations shows that 3 identical species occur in the Helderbergian series; 1 identical, in the Oriskany; 6 identical, in the Schoharie; 17 identical, doubtfully 4 more, and 2 affiliated, in the Onondaga; 47 identical, 1 more doubtfully, and 7 affiliated, in the Marcellus; 92 identical and 32 affiliated, in the Hamilton; 2 identical, in the Tully; 4 identical and 1 affiliated, in the Genesee; 2 identical, in the Portage; 4 identical and 2 affiliated, in the Naples; 10 identical and 1 affiliated, in the Sherburne; 55 identical, 2 more doubtfully, and 9 affiliated, in the Ithaca; and 18 identical, 4 more doubtfully, and 3 affiliated, in the Chemung. Adding these numbers, the total number of entries for each New York formation is as follows: Helderbergian series, 3; Oriskany sandstone, 1; Schoharie grit, 6; Onondaga limestone, 23; Marcellus shale, 55; Hamilton beds, 124; Tully limestone, 2; Genesee shale, 5; Portage beds, 2; Naples beds, 6; Sherburne sandstone, 11; Ithaca beds, 66; and the Chemung beds, 25. Judging from the number of entries, it is then seen that the Maryland beds show the closest relationship with the Onondaga, Marcellus, Hamilton, Ithaca, and Chemung formations of New York; and especially with the Marcellus, Hamilton, and Ithaca. On examining the total number of entries for these three formations, it is found that the Marcellus has 44.3 per cent. as

many as the Hamilton, and the Ithaca 52.8 per cent. This is not remarkable, however, when it is recalled, in the first place, that a large percentage of the species in the Marcellus shale of New York continue into the Hamilton beds of that state, as has been shown by Dr. John M. Clarke; and, in the second place, that the Ithaca fauna is sequential to the Hamilton, and in the Ithaca region contains a large percentage of Hamilton species. When followed to the eastward, and after the disappearance of the Tully limestone and Genesee shale in the Chenango valley, the writer has shown that a still larger number of the Hamilton species lived into Ithaca time, although part of them were represented by simply a few individuals which were the last feeble representatives of their species. These rare individuals have been recorded in the range of the species, making the faunas of the Hamilton and Ithaca beds of New York seem more closely related than they actually are; and the same is true regarding the faunas of the Maryland beds and the Ithaca beds of New York. This explanation is sufficient to show that the above tabulation gives full expression to the closeness of the relationship which exists between the fauna of the Maryland beds and the faunas of the Marcellus shale and Ithaca beds of New York, as compared with that which exists between the fauna of the Maryland beds and the New York Hamilton fauna. Restating the tabulation, then, it is shown that there are more than twice as many entries common to the Maryland and New York Hamilton beds than to the Maryland and New York Marcellus; and nearly twice as many for the Maryland and New York Hamilton beds as for the Maryland and New York Ithaca. Therefore the paleontological evidence strongly supports the correlation of the Maryland beds, which represent in general the midddle and upper portions of the Romney formation, with the Hamilton beds of New York.

Recently Professor H. S. Williams has published an extended account of what he calls the *Tropidoleptus carinatus* fauna of the Hamilton formation.[1] Faunally he considers the Hamilton formation as including the deposits between the top of the Onondaga limestone and the base of the Tully limestone of central New York, which

[1] *American Journal of Science*, Fourth Series, Vol. XIII (1902), pp. 421–32; *Bulletin No. 210*, U. S. Geological Survey, 1903, pp. 42–68.

have generally been divided into the Marcellus shale and the Hamilton beds. Professor Williams compiled a list of twelve species for the *Tropidoleptus* fauna which he called the "standard list of dominant species for the New York-Ontario province." Another list was also compiled, which he called a "revised list of dominant species of the Hamilton formation of eastern New York and Pennsylvania, as expressed in 183 faunules," which contained the twelve species given in the standard list and four additional ones. All of these sixteen species occur frequently in the Hamilton beds of Maryland.

Professor Williams, after an examination of the preliminary lists from the Hamilton beds of Maryland, published the following statement:

> In the list furnished me by Professor Prosser there appear 132 entries, 91 of which are positive identifications. Among the latter are found all of the dominant species of the *Tropidoleptus carinatus* fauna, as estimated from the New York statistics. This is sufficient to establish the extension of the *Tropidoleptus* fauna, in its integrity, as far south in the Appalachian trough as Maryland.[1]

Other facts brought out in the Maryland Devonian report by Dr. John M. Clarke and the writer apparently show that the Hamilton beds of Maryland are succeeded by deposits and faunas similar to those succeeding the Hamilton of New York, and therefore it may be concluded that the deposits of the Hamilton beds from New York to West Virginia were brought to a close at about the same geological time.

EUROPEAN EQUIVALENTS.

The early attempts at correlating the Devonian rocks of the United States with those of Europe dealt only with the formations found in New York, which, in fact, has generally been the custom down to the present time. In 1842 Conrad published the statement that "the Ithaca group, Chemung group, and the Old Red Sandstone near Blossburg, in Pennsylvania, constitute the equivalents of the Devonian system as developed in Europe," and contain a number of fossils characteristic of European Devonian strata.[2] The same year Vanuxem stated that the last three groups of the "Erie Division"

[1] *Bulletin No. 210*, U. S. Geological Survey, p. 67.

[2] *Journal of the Academy of Natural Science*, Philadelphia, Vol. VIII, p. 232.

—viz., the Portage, Ithaca, and Chemung—"appear to correspond with the Devonian system of Mr. Phillips."[1] The following year Professor Hall gave the base as somewhat lower when he stated that the Devonian system appears "to correspond to the Chemung and Portage groups, and also to include a portion of the Hamilton."[2] In 1847 Professor Hall stated that

> With the Schoharie grit, commences a series of strata containing fossils as distinct from those of the preceding formations, as these are from the lower division. We here, for the first time, recognize several species that are regarded as Devonian forms; and if zoölogical characters are to be paramount, we are compelled to unite all the succeeding strata as of Devonian age.[3]

Finally in 1859, he raised the question whether even the Oriskany sandstone might not be considered as of Devonian age. For he wrote as follows concerning

> the line of demarkation for the Silurian and Devonian systems. Shall the advent of the Oriskany sandstone, with its *Spirifer* of dichotomizing costæ, be the division? Or shall we look for some more marked and more readily defined and recognized feature for the distinction between what are regarded as two great geological systems?[4]

So far as the writer is aware, de Verneuil in 1847 was the first geologist definitely to correlate the younger formations of the New York system with subdivisions of the Devonian system of Europe. He made the base of the Oriskany sandstone the dividing line between the Devonian and Silurian systems;[5] correlated the Hamilton, Tully, Genesee, Portage, and Chemung with the formations of the Eifél and Devonshire, and the Marcellus with the shales of Wissenbach in Nassau, as is proved by their Goniatites, so analogous in form.[6]

In recent years several geologists have considered the correlation of the American Mesodevonian with European rocks of equivalent age, of which the following are the most important:

[1] *Geology of New York*, Part III, p. 171.

[2] *Ibid.*, Part IV, p. 20.

[3] *Palæontology of New York*, Vol. I, p. xvii.

[4] *Ibid.*, Vol. III, Part I, p. 42.

[5] *Bulletin de la Société Géologique de France*, Second Series, Vol. IV, p. 677; also *American Journal of Science*, Second Series, Vol. V (1848), p. 367, on the parallelism of the Palæozoic deposits of North America with those of Europe, translated by JAMES HALL.

[6] *Loc. cit.*, p. 678; and *American Journal of Science, loc. cit.*, pp. 367, 368.

In 1889 Professor H. S. Williams apparently correlated in a general way the American Middle Devonian with "the Ilfracombe [England] beds of Phillips, the Givétien limestone of Belgium, [and] the Stringocephalien shales or limestones of the Eifél and Hartz regions."[1] In 1888 Professor Williams examined in the field typical sections of the Devonian rocks of Devonshire, England, and later stated that "it appears probable that the limestones of South Devonshire represent the general interval between the close of our Corniferous [Onondaga] and the early part of our Chemung formation."[2] Professor Renevier in 1896 classed the Hamilton flags and Marcellus shales together and regarded them as having been deposited during the same general period of time as the *Tentaculite* slates (lower part) of Thuringia, Hesse, Nassau, and Bohemia; the Wissenbach or *Orthoceras* slates of Nassau; the Lenne slates (in part) of southern Westphalia; and the schists with *Phacops potieri* of Brittany; all of which were correlated with the Couvinien age or stage, which he gave as the lower one of the Middle Devonian or Eifélien epoch or series.[3]

Dr. Frech draws the line between the Paleodevonic and the Mesodevonic of New York at the top of the upper Oriskany sandstone, and considers the Mesodevonic as composed of the Ulsterian and Erian seris, in the latter of which are the Marcellus shales, Hamilton beds, and *Stringocephalus* beds of Canada.[4] At an earlier date Dr. Frech, in his summary of the important occurrences of the Devonian, gave the Marcellus shale and Hamilton group as forming the upper part of the Middle Devonian, and correlated them as beginning in the time of the upper part of the *Calceola sandalina* stage and continuing through that of the *Stringocephalus burtini* of Rheinland.[5] In this same table the Marcellus and Hamilton considered together are correlated with the upper part of the Eifélien (*Calceola* shales

[1] *Compte rendu*, Fourth Session, International Geological Congress (London, 1888), 1891, Appendix A, p. 142; also issued as *Report of the Sub-Committee on the Upper Paleozoic (Devonic)*, by H. S. WILLIAMS, C, 1889, p. 22.

[2] *American Journal of Science*, Third Series, Vol. XXXIX (1890), p. 36.

[3] *Chronographe géologique*, 2d ed. of *Tableaux des terrains sedimentaires; Compte rendu*, Sixth Session, International Geological Congress (Zurich, August, 1894); Lausanne, March, 1897).

[4] *Lethaea geognostica*, I, *Lethaea palaeozoica*, Vol. II, Part IV (1902), p. 690.

[5] *Ibid.*, Vol. II, Part I (1897), Table XIX, opposite p. 256.

of Couvin) together with the entire Givétien (which is composed in ascending order of the red sandstone and conglomerate of Vicht and *Stringocephalus* limestone of Givét) of Belgium; while they are given as equivalent in England to the Ilfracombe beds, with probably additional ones below and above, of North Devon; and to the upper part of the *Calceola* shales of Hopes Nose and Ogwell House, succeeded by the diabase and scale stone of the Ashfrington series and the *Stringocephalus* limestone of South Devon.

In another part of the work Dr. Frech, in comparing the North American and Rhenish Devonian, said:

> In the Corniferous [Onondaga] limestones the faunal diversity is less sharply defined than in the lower formations; but in this case, as in the higher Hamilton group, still distinctly perceptible. The latter is often developed in the form of sandy marl and calcareous sand, and the peculiar faunal similarity with the Rhenish Lower Devonian partly rests upon this harmony in facies. But, on the other hand, the marl (Moscow shale), for example, where it forms on Cayuga Lake the greater part of the Hamilton, has a perfect agreement in facies with the *Calceola* marl, and likewise the Encrinal limestone reminds one of a similar interstratified limestone. . . . . The fauna of the American Middle Devonian, whose chief representatives the Hamilton group contains, is, notwithstanding some corresponding features, yet, on the whole, so different that one must assume the existence of a special sea province also in Middle Devonian time differing from the Rhenish.[1]

Finally, at the close of this section is the statement that the Marcellus shale corresponds to the lower part of the stage of the *Maeneceras terebratum*[2] of Rheinland, which Dr. Frech puts in the stage of the *Stringocephalus burtini*.

De Lapparent considers the Middle Devonian of North America as composed of the Corniferous (Onondaga) limestone, Marcellus shale, and Hamilton beds.[3] The Marcellus shale he correlates with the upper part of the Eifélien stage and the lower part of the Givétien, while the Hamilton beds represent the remaining and greater part of the latter stage. He also gave the lower Marcellus shale as representing the upper part of the shales of Ogwell House, and then the remaining portion together with the Hamilton beds as synchronous with the Ilfracombe or Plymouth beds of Devonshire, England.[4]

Professor Kayser in the table of the Devonian formations of New

[1] *Ibid.*, pp. 214, 215.
[2] *Ibid.*, p. 216.
[3] *Traité géologique*, 4th ed. (1900), p. 857.
[4] *Ibid.*, p. 869.

York, gives the Mesodevonic as composed of the Marcellus shale and Hamilton beds,[1] but in the text he says:

> The American geologists generally still classify the Onondaga limestone as Lower Devonian; according to European experience, one would be rather inclined to classify it entirely or mostly as Midddle Devonian. The great similarity of the characteristic *Spirifer acuminatus* Con. with our *S. cultrijugatus* argues for this classification.[2]

Regarding the classification of the Hamilton the professor says:

> Although the Hamilton shale locally might represent the entire Middle Devonian, yet, on the whole, it corresponds to the upper division. This is surely shown by the frequent overlying beds of the Tully limestone and Genesee shale, the first of which contians the Brachiopod fauna of our Iberg limestone (*Rhynchonella venustula=cuboides*, etc.).[3]

Finally, this writer has given the correlation of the Middle Devonian of Europe and North America in the following table:

RHEINLAND AND BELGIUM.		BOHEMIA.	NORTH AMERICA.
		G^3,	
Stringocephalus limestone, Caleceola shales.	Wissenbach and Lenne slates.	G^2, G^1, Mnenian limestone.	Hamilton beds, Marcellus beds, Onondaga limestone[4]

Dr. Hermann Credner gives the Middle Devonian of New York as composed in ascending order of the Upper Helderberg (Onondaga), Marcellus shale, and Hamilton sandstone, shale, and limestone. The Upper Helderberg he correlates with the Eifélien and stage of the *Calceola sandalina*, and the Marcellus and Hamilton with the Givétien and stage of the *Stringocephalus burtini*.[5]

Sir Archibald Geikie considers the Middle Devonian of New York as composed of the Marcellus and Hamilton groups,[6] while the same division in Europe he gives as composed of the Eifélien and Givétien, with which he correlates the Marcellus and Hamilton.[7]

GENERAL DISTRIBUTION OF THE MESODEVONIAN.

Rocks of the Mesodevonian age have a considerable distribution, aside from that of the eastern United States and Canada, for they

[1] *Lehrbuch der geologischen Formationskunde*, 2d ed. (1902), p. 150.
[2] *Ibid.*, p. 151. [3] *Ibid.*, p. 151. [4] *Ibid.*, p. 155.
[5] *Elemente der Geologie*, 9th ed. (1902), p. 447.
[6] *Text-Book of Geology*, 4th ed., Vol. II (1903), p. 997.
[7] *Ibid.*, "The Geological Record," opposite p. 861.

have been identified and described in Nevada; the dolomite of Manitoba contains the European species *Stringocephalus burtini; Spirifer mucronatus* has been found upon the banks of the Albany River south of Hudson Bay; the fauna of the Hamilton shales occurs in the Mackenzie Valley from the Clear Water River to the Arctic Ocean; while it is also reported from the Porcupine River, a western tributary of the Yukon in Alaska, and perhaps also on Kouiou Island, in the southern part of that territory. In South America, in Brazil, in the province of Para, in the Ereré district, are beds which Katzer refers to the base of the Middle Devonian, and Dr. J. M. Clarke has stated regarding the fauna of the Ereré sandstone that it

> is remarkably free from species or representatives of subgeneric groups prevailing elsewhere in early Devonian faunas, and equally devoid of types which elsewhere pass upward into the later faunas; in other words, it is, with all its resemblance to the Hamilton, a more typical and better-defined Middle Devonian fauna than that;[1]

while Dr. Frech reports Middle Devonian in Bolivia and Cleland from the Jachel River in Central Argentina.[2] On the eastern continent Middle Devonian rocks occur in England in northern and southern Devonshire, in northern France and southern Belgium, in the region of the Vosges, in the Central Plateau and the Montagne-Noire of France, and in the Pyrenees and Spain. In central and eastern Europe they occur in the Eifel, Rheinland (Nassau), Hartz, Thuringia, Bohemia, Galicia, Russian Poland, the Carnic Alps, and on the Bosporus. These rocks also cover a large area of eastern Russia and the western slope of the Urals, extending to the border of Finland on the north. In Asia Middle Devonian rocks occur in Siberia, China, and on the south side of the Tian-Shan Mountains in Central Asia. In Australasia they are found in New South Wales, Victoria, and Tasmania; and they also probably occur in Africa.[3]

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Columbus, Ohio, July, 1904.

[1] *Archivos do Museu Nacional do Rio de Janeiro.* Vol. X (1899); author's English edition (1900), p. 90.

[2] *Bulletin No. 206,* U. S. Geological Survey, (1903) p. 19.

[3] For this account of the distribution of the Mesodevonian the writer is largely indebted to DE LAPPARENT'S *Traité de géologie,* FRECH'S *Lethaea palaeozoica,* and KAYSER'S *Lehrbuch der geologischen Formationskunde.*

GRANITES OF NORTH CAROLINA.[1]

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[1] Published by permission of the state geologist of North Carolina.

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INTRODUCTION.

The following paper is based on a study of the granites and gneisses of North Carolina during the past field season, while I was engaged on the State Geological Survey in a field study of these rocks. The economic report treating of the granites has been prepared and will form a part of a general report on the building-stones of North Carolina to be published by the State Survey. A general summary setting forth the more important points in the petrography and structure of these rocks is offered in the present paper as a separate contribution.

DISTRIBUTION OF THE GRANITES.

North Carolina is divisible naturally into three principal physiographic provinces, which, named in order from east to west, are: the Coastal Plain, the Piedmont Plateau, and the Appalachian Mountains. These form a part of the continuation of the same provinces to the north and south of North Carolina; and they observe approximate parallelism with each other and with the general trend of the coast line of the southeastern Atlantic states. The granites of North Carolina are distributed over parts of each of these three provinces; the areas being fewer and smaller over the Coastal Plain region, and more numerous and larger over the Piedmont Plateau region. Gran-

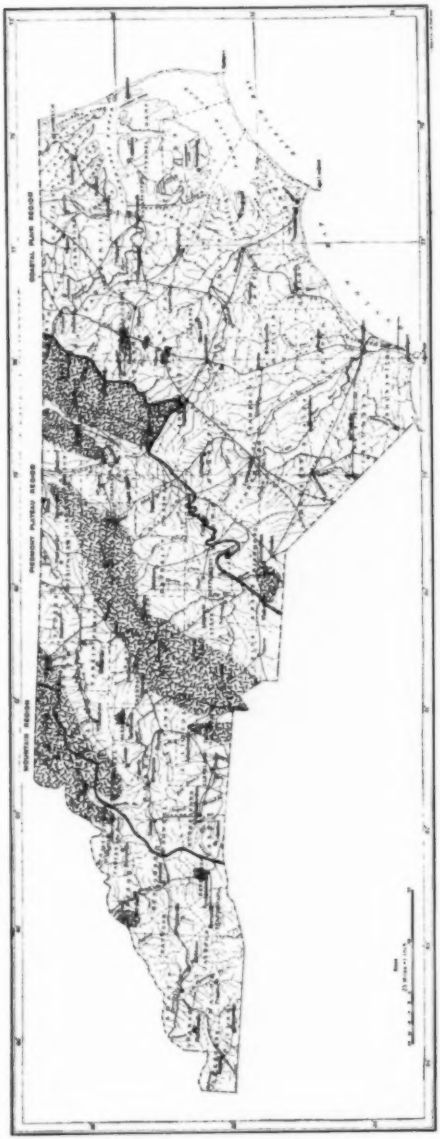

FIG. 1.

ite is extensively developed in many places, within the limits of the Piedmont Plateau, and it forms over many parts of the plateau one of the dominant rock types. The distribution of the principal granite areas of the state is shown on the accompanying map.

Over all parts of the state the rocks are profoundly decayed from weathering and, as a rule, are buried under a deep mantle of loose residual decay. Notwithstanding the extensive decay of the rocks, exposures of the moderately fresh granite are comparatively numerous and assume oftentimes very large dimensions. The granite forms unreduced residuals or ridges, as shown in Fig. 7, and it is further exposed in bowlders and ledges and flat-surface masses, both along the stream courses, and more or less remote from the streams on the interstream areas. (Figs. 2 and 3.)

Numerous quarries have been worked in the outcrops of granite throughout the state, and the stone has been used for all purposes for which granite is ordinarily adapted.

TYPES OF THE GRANITES.

Based on texture and structure three types of the granitic rocks are distinguished: (1) the massive even-granular (normal) granites; (2) the porphyritic granites; and (3) the banded or schistose granites—granite-gneiss. Field and laboratory study develops close similarity in the three types in mineral composition, and, with one exception, the even-granular and porphyritic textures represent different phases of the same rock-mass. Moreover, the granite-gneisses differ essentially from the massive granites, from which they have been derived, only in the pronounced schistose structure subsequently induced by pressure-metamorphism.

NORMAL GRANITES.

The even-granular granites have wide distribution, and they compose largely the bulk of the granites occurring in North Carolina. As a rule, they vary from fine- to medium-textured rocks, rarely coarse, and are of pink to gray color. With only a few exceptions, light to medium and dark gray is the prevailing color of the granites. Variation in structure is from massive to schistose rocks. They are mixtures of orthoclase and plagioclase feldspars and quartz, with a

variable quantity of biotite and, in places, some additional hornblende as the characterizing accessories. The prevailing large amount of plagioclase feldspar in the rocks is a very noteworthy feature; rarely does this constituent sink to very subordinate proportions, but usually it is almost equal to, or even exceeds in amount, the potash

FIG. 2.—Granite bowlders on Dunn's Mountain, near Salisbury, North Carolina. Showing weathering along the joint-planes.

feldspars; and only in a few of the sections studied does it entirely fail. In many of the areas the poverty of the rocks in the ferromagnesian silicates is a striking feature—a fact well illustrated in the large and important granite area in Rowan county, known as Dunn's Mountain, and its southwestern extension.

PORPHYRITIC GRANITES.

In all respects save that of texture the porphyritic granites are identical with the normal granites. They are usually coarser in texture than the even-granular rocks, but mineralogically the two are

identical. With one exception, the two textures grade one into the other, representing different textural phases of the same rock-mass.

Porphyritic granites have wide distribution over the state in association with the even-granular phases of the rock. The most important areas are: (1) The Wadesboro-Rockingham area to the east of Charlotte and near the South Carolina line, extending over contiguous parts of Anson and Richmond counties. Over parts of this area the feldspars are colored a rich olive-green, representing apparently a superficial phenomenon caused by some form of surface alteration. A second difference noted is in the distribution and character of the biotite, which occurs in hexagonal plates of single or grouped individuals occupying distinct areas. (2) The Gastonia area in Gaston county, west of Charlotte. (3) The Mooresville area in Iredell county. (4) The Cabarrus county area, three miles southwest of Concord; and a second area in the same county in the vicinity of Landers station on the Southern Railroad, to the north of Concord and near the Rowan county line. The porphyritic rock occurring three miles southwest of Concord is quite different in appearance from that of any other area of porphyritic granite known in the state. Here the rock is uniformly coarse-textured and largely feldspathic, composed of large bluish-gray feldspars without pronounced crystal outline. The rock contains hardly more than a trace of groundmass, but is made up chiefly of the large feldspars wrapped about each other and closely interlocked. Biotite in small irregular shreds is one of the chief minerals in the scant groundmass. (5) The Salisbury area, which forms one of the most extensive belts in the state and is traced over parts of Rowan, Davie, and Forsyth counties. Smaller and less important areas of similar porphyritic granite have been noted in several other counties in the state.

Excepting the area three miles southwest of Concord in Cabarrus county, the porphyritic granite of the different areas mentioned above is closely similar in color, texture, and mineral composition. The groundmass is usually a medium-coarse gray granite composed of feldspar, quartz, and biotite. Some variation in the amount of the last constituent, biotite, is noted from place to place, resulting in a corresponding variation of color from light to dark gray. The porphyritically developed mineral is potash feldspar. As a rule,

phenocrysts are marked in the different areas by idiomorphic outlines; and they are prevailingly of large size, measuring in extreme cases more than two inches long by one inch across. They are usually white, with pinkish ones not uncommon, and, in most cases, they contain more or less included biotite, frequently as large in size as

FIG. 3.—Granite pinnacle on the west slope of Dunn's Mountain, near Salisbury, North Carolina. Height of pinnacle more than twenty-five feet.

that of the groundmass constituent. Under the microscope other inclusions of the groundmass constituents are contained in some of the phenocrysts. For this and other reasons elsewhere[1] stated by me, the phenocrysts of the Carolina porphyritic granites are regarded as having been formed largely, if not entirely, *in place* and not as often urged of *intratelluric* origin.

Generally the phenocrysts do not grade into the similar groundmass constituent, but they are, in most cases, conspicuously developed

[1] "On the Origin of the Phenocrysts in the Porphyritic Granites of Georgia," JOURNAL OF GEOLOGY, Vol. IX (1901), pp. 97–122.

and are sharply defined from the groundmass feldspar. No marked or definite orientation has been observed among the phenocrysts in any of the areas, but in some of the exposures a slight tendency toward such was indicated. Flow structure in the groundmass is entirely absent from all of the areas studied.

The porphyritic feldspars almost entirely fail in places, reappearing again within a short distance in their usual abundance and of conspicuous development. Over most of the areas the probable average ratio of phenocrysts to groundmass is approximately one to one, though extreme variations from this ratio in either direction occur. In the transitional phases of the rock where gradation from the porphyritic to the even-granular texture is observed, the phenocrysts are so few and are so widely scattered that the rock could hardly be termed porphyritic. On the other hand, in the porphyritic granite area three miles southwest of Concord, in Cabarrus county, the rock is composed almost entirely of the large feldspar individuals with very scant groundmass. In all cases the phenocrysts display good cleavage development and twinning on the Carlsbad law.

In many of the areas where outcrops of the fresh or moderately fresh granite are few, the rock can be traced almost as readily by its residual decay. The loose phenocrysts are scattered over the surface in places in a partially altered condition, often split into smaller fragments along the cleavage directions.

Relations between the porphyritic and the even-granular granite in the Mooresville area.—Like the other areas studied, the porphyritic and non-porphyritic granite of the Mooresville area differ from each other only in texture. Without going into detail descriptions of the two texturally unlike rocks, evidence is afforded at several places to the south and the southwest of Mooresville for regarding the one as intrusive in the other, and they do not represent separate facies of the same granite mass. Were the latter true, the line between the two rocks should mark a transitional zone from the porphyritic to the non-porphyritic granite, and not indicate in the few exposures examined a sharp contact. Furthermore, certain phenomena along this line would be difficult of explanation on this supposition. On the other hand, the evidence strongly suggests that the porphyritic rock is the oldest, and that the even-granular granite is intrusive in it. The field

evidence supporting this belief may be summarized as follows: the sharpness of contact between the porphyritic and the non-porphyritic granite; the prevailing coarser texture of the porphyritic granite along the line of contact than that of the non-porphyritic rock; the banding in places along the contact; inclusions of the porphyritic granite in the even-grained granite; and the occurrence of probable apophyses of the fine-grained granite penetrating the porphyritic granite.

GRANITE-GNEISS.

True granite-gneisses are found in many places over the state, but perhaps the most typical areas are: (1) the unreduced residual locally known as Rockyface Mountain in Alexander county; (2) the area near Balfour station in Henderson county; and (3) the area on the Josey-Bogers places, three miles southwest of Faith in Rowan county. Wherever studied, the granite-gneisses are biotite-bearing, fine to medium texture, and closely resemble the massive granites in all essentials except that of schistose structure. Some effects of pressure-metamorphism are indicated either megascopically or microscopically in the granites of most of the areas studied. Granites of complete schistose structure were not definitely traced in any single area into entirely massive ones, although this may be the real condition in many cases. Lack of sufficient exposures of the rocks renders this uncertain in the North Carolina areas.

RELATIONS BETWEEN THE THREE TYPES OF GRANITE.

Enough description has been detailed above under the even-granular, porphyritic, and schistose granite to make fairly clear, so far as the field study is possible, the relations between the three texturally and structurally unlike granites here distinguished. It seems reasonably certain, so far as I have been able to interpret the field relations, that the porphyritic and non-porphyritic granites represent, with one or two possible exceptions different facies of the same granite mass. The principal exception noted above is that of the Mooresville area in Iredell county, where the normal granite is intrusive in the porphyritic granite.

The exact relations of the schistose (granite-gneisses) to the even-granular massive granites are less clear, and for lack of adequate

exposures no definite statement can be made regarding whether the granite-gneisses are the more schistose transitional portions of a more massive granite stock. The completely schistose structure has nowhere been positively traced into the more massive granites, though this may be the true relation. That the areas of schistose granites mentioned above are the metamorphosed equivalents of the massive granites apparently admits of no reasonable doubt.

As pointed out in my study of the Georgia granites,[1] the exact relationship is an important one as bearing on the question of the relative age of these rocks. If the schistose rocks (granite-gneisses) cannot be traced into granites of more massive structure, but the two are separate and distinct, then clearly two periods of intrusion must be admitted, separated by an interval of intense pressure-metamorphism, which resulted in inducing the secondary schistose structure in the earlier massive granites, represented, if the postulate is correct, by the present granite-gneisses. If, on the other hand, the two represent phases of the same rock-mass in which the action of dynamic forces has been greater in some parts of the massif than in others, then the same age must be assigned them. As elsewhere shown in my study of the Georgia granites, the first condition apparently obtained, and the granites are not all of the same age, but at least two separate periods of intrusion of nearly identical material are indicated.

GRANITES OF THE COASTAL PLAIN REGION.

GENERAL CHARACTERS.

The line marking the contact between the Coastal Plain and the Piedmont Plateau formations in North Carolina is a very irregular one. It enters North Carolina from Virginia a short distance east of the Warren county line and crosses the state in a general southwest direction, passing into South Carolina a short distance southwest of Wadesboro. To the east of this line are the loose unconsolidated formations of the Coastal Plain.

In many places near the contact of the Coastal Plain formations with the rocks of the Piedmont Plateau, but falling well within the

[1] "Granites and Gneisses of Georgia," *Bulletin No. 9-A*, Geological Survey of Georgia, 1902.

limits of the former, the thin veneer of loose unconsolidated sands and gravel has been stripped from the surface, mainly along the streams, exposing comparatively small, irregular, somewhat elongate areas of the crystalline rocks, composed either in part or in whole of granite. In such areas the general nature of the granite exposures is in the form of ledge and bowlder outcrops, and as flat-surface masses a short distance back from the streams.

The inliers of crystalline rocks mark the eastward extension of the Piedmont crystallines beneath the Coastal Plain sediments. Some of the schists and gneisses composing parts of these areas are the metamorphosed equivalents of original igneous masses. They include both acid and basic types.

The principal granite areas of the Coastal Plain are exposed in Wilson, Edgecombe, and Nash counties to the east of Raleigh, and in Anson and Richmond counties in the vicinity of Wadesboro near the South Carolina line. They are composed of massive biotite granites, in one instance hornblende-bearing, which vary from fine even-granular to coarse porphyritic rocks of gray to pink color. The area to the north of Elm City, in the extreme northern part of Wilson county, contains some hornblende in addition to the biotite.

LITHOLOGICAL CHARACTERS OF THE GRANITES.

The Coastal Plain granites are described separately by areas in order to bring out more clearly their close similarity to the granites of the Piedmont region.

The Wilson pink granite area.—The rock is uniformly coarse-textured, of moderate pinkish-red color, and displays a pronounced porphyritic tendency. Feldspar is greatly in excess of the other minerals. The largest feldspar individuals measure one to two inches long. They are pinkish-red in color, exhibiting good cleavage development and twinned on the Carlsbad law. Microscopically the feldspar and quartz make up not less than 95 per cent. of the rock. A rough estimate indicates about 80 per cent. of the former and 15 per cent. of the latter. Of the feldspathic content about 50 per cent. is potash feldspar, most of which is orthoclase, with but little microcline; and 30 per cent. is plagioclase in very large, finely striated laths, whose extinction angles measured against the twinning bands indicate

albite. Biotite is but sparingly present in the rock and is largely altered to chloride. Occasional small grains of magnetite and scattered inclusions of prismatic apatite, with some secondary muscovite, kaolin, and calcite, complete the list of accessories.

The weathered surface of the granite is light in color. The feldspars are dull and opaque, and have lost much of their decided pinkish-red color, so characteristic of the same constituent in the fresh rock.

The Elm City area.—The Elm City granite is strongly contrasted with the Wilson pink granite described above. It is much finer in texture, of gray color, and contains more biotite and quartz than the Wilson pink granite. Feldspar predominates and consists of the potash varieties and much striated acid plagioclase. Extinction angles measured on the plagioclase correspond to an albite of the composition $Ab_{12}An_1$. Areas showing alteration to kaolin and muscovite cloud some of the feldspars. Micropoikilitic structure is strongly developed in some of the larger individuals of potash feldspar, the inclusions of which consist of large microscopic grains of quartz and striated feldspar. Quartz is of the usual kind, forming distinct areas of an interlocking finer mosaic. Biotite is distributed through the sections as small plates of brown color and strong pleochroism, bleached to green on alteration, and is further altered to chlorite and some epidote. In one of the thin sections a few additional small crystals of compact hornblende, showing the usual development of the prismatic cleavages, occur. The principal accessories include zircon, apatite, a little pyrite, titanite, and ilmenite. The granite shows evidence both megascopically and microscopically of dynamic metamorphism, manifested, in places, by a rather pronounced schistose structure.

The quarry opening indicated penetration of the granite by a dike of very finely schistose amphibolite, closely jointed and containing many disseminated small grains of pyrite. Additional quartz veins penetrate the granite, wrapped, in cases, by films of thin layers of hornblende. The surfaces of the joints are slickensided, coated with a thin veneer of yellowish-green mineral substance, probably epidote in part. Considerable epidotization characterizes the rock in places.

The Rocky Mount area.—Westward from Rocky Mount the granite is associated with an irregular but large body of crystalline schists

which were derived in part from original igneous rocks. Contacts between the granite and the schists were nowhere observed, but the field evidence clearly suggests that the granite is the younger rock.

Pegmatite veins, ranging from a fraction of an inch to more than six inches across, composed of pinkish feldspar and quartz, with a very subordinate amount of biotite, penetrate the granite. Nearly all gradations from those veins containing mostly feldspar to those containing mostly quartz occur. In some of the veins the quartz forms a narrow central band in the feldspar. Others still are banded with a fine-textured granite of the same mineral composition as the inclosing rock. Some of these are true veins of segregation; others are less certain of interpretation, mainly because of the lack of exposures for examining them.

Megascopically the rock is somewhat unlike that described above, the Elm City area. It is entirely massive, of medium texture, and gray color. In mineralogy it differs from the Elm City rock in the entire absence of hornblende, and in the presence of only a slight amount of plagioclase. Orthoclase and microcline have nearly equal distribution. Quartz forms a fine mosaic, occupying distinct areas. Intergrowths of micrographic structure are rather abundantly distributed through the sections in irregular small areas. The accessory minerals are biotite, chlorite, epidote, apatite, zircon, and magnetite.

The Wadesboro-Rockingham porphyritic granite area.—This is a large area of porphyritic granite lying partly in Anson and partly in Richmond county, near the South Carolina line and to the west of Charlotte. About one mile east of the westernmost exposure of the granite the Triassic sandstones first appear, overlying unconformably the crystalline schists. Between the granites and the sandstones is an area of variable crystalline schists, principally micaceous and quartz schists. Between Rockingham and the easternmost outcrops of the granite the rocks are concealed by Coastal Plain sands and afford no evidence of the nature of the underlying crystallines. In and about the town of Rockingham the principal outcrops indicate a greenstone schist much crushed and fractured, and strongly suggests derivation from an original basic igneous rock. The schists to the east and west of the granite mass must be regarded as older in age

than the granites, and they form the country rock into which the granite was intruded.

Exposures of the granite are in the nature of huge bowlders, ledges, and flat-surface masses. Sections of the fresh and weathered granite are seen to advantage in the cuts along the Seaboard Air-Line Railroad to the east and west of Lilesville.

It is a coarse-grained porphyritic biotite granite of gray color, with pinkish and yellow tones characteristic in places. The groundmass is medium coarse-textured, dark gray, granite, containing, as a rule, much biotite. This is subject, however, to some variation. In the railroad cut one and a half miles west of Lilesville the biotite has quite a different occurrence and distribution in the granite from that of any other exposure examined in the area. Here the biotite is usually in sharp idiomorphic hexagonal plates, distributed through the rock as single individuals and aggregates, which occupy distinct areas. Elsewhere it occurs as irregular shreds crowded close together and freely distributed through the groundmass.

The phenocrysts are composed of potash feldspar, showing marked cleavage development and twinned on the Carlsbad law. They are usually of a pinkish hue, and may be either idiomorphic or allotriomorphic in outline; and, they contain usually some included biotite. The ratio of phenocryst to groundmass is variable, but will probably average about one to three.

The principal minerals are quartz, orthoclase, microcline, plagioclase (near oligoclase), biotite, chlorite, apatite, zircon, magnetite, and a few other less common accessories. Microcline may fail in some sections and be present in large proportion in others. Plagioclase is a constant constituent and is usually present in large amount.

GRANITES OF THE PIEDMONT PLATEAU.

GENERAL CHARACTERS.

The Piedmont region in North Carolina is composed of a number of geologic belts, approximately parallel to each other and crossing the state in a general northeast-southwest direction. These belts are composed, as a rule, of unlike rocks, probably of different ages. A variety of granites are found within the limits of the Plateau region; always biotite-bearing, with additional hornblende in some areas,

and muscovite when present in very subordinate amount. In texture, variation is from even-granular to porphyritic; and in structure from massive to schistose. As a rule, some shade of gray prevails, though pink is largely characteristic of certain areas. The Plateau granites are described under the following belts: The Northeastern Carolina Granite Belt, the Main Granite Belt, and the Western Carolina Gneiss and Granite Belt.

THE NORTHEASTERN CAROLINA GRANITE BELT.

This area comprises a part or the whole of five counties located in the extreme northeast part of the Piedmont region, extending northward from Raleigh. With but few exceptions, the granites of this belt are partially schistose in structure. The characterizing accessory, biotite, is variable in quantity; imparting accordingly either a light or a dark gray color to the rock. In places the feldspars are of a pronounced pinkish hue and with the subordinate amount of biotite present, the rock assumes more or less of a mixed pinkish-gray color. The granites are usually even-granular in texture, though the porphyritic tendency is somewhat emphasized in places. They do not differ essentially in mineralogy, although hand specimens from different areas in the belt may bear no resemblance to each other.

LITHOLOGICAL CHARACTERS.

Two areas, differing somewhat widely in the hand specimens, but which may be regarded as representative of the granites of the belt as a whole, are selected for description, in order to make clear the general characters of the rocks as a whole. These are the Raleigh area in Wake county and the Greystone area in Vance county.

The Raleigh area.—Studied in the quarries opened within the eastern limits of the city of Raleigh, the rock is a fine even-textured, medium-gray, biotite granite-gneiss, completely interlaced by intersecting pegmatites. The principal minerals are quartz, orthoclase, microcline, acid plagioclase near oligoclase, brown biotite, muscovite, zircon, apatite, chlorite, and epidote. Quartz is of the usual kind, and is often intergrown with feldspar in micrographic structure, clearly indicating that its period of formation began before that of the feldspar closed. In addition, it occurs with other minerals, especially

plagioclase, in the form of inclusions in the larger potash feldspar individuals developing micropoikilitic structure. Microcline nearly equals orthoclase in quantity, and plagioclase is hardly less than both. Carlsbad twinning is sometimes observed in the feldspar.

Biotite is brown in color, strongly pleochroic, and is largely altered to chlorite and some epidote. An occasional shred of muscovite is intergrown with the biotite. The other accessory minerals present no noteworthy features.

The larger feldspar and quartz individuals are partially or entirely surrounded by finer mosaics of the same minerals, denoting peripheral shattering from dynamic forces. Strained shadows in the minerals are further characteristic of the same pressure effect.

In the northern part of Wake county, in the vicinity of Rolesville, a light pinkish biotite granite occurs, which differs from the Raleigh granite in the hand specimen, but does not differ essentially in mineralogy. Plagioclase is very variable, equaling in some sections the potash feldspar and nearly failing in others. Orthoclase and microcline are in nearly equal proportion. Small irregular areas of micrographic intergrowths of quartz and feldspar are quite abundantly distributed through the thin sections.

The Greystone area.—The Greystone quarries are among the largest in the state. The typical Greystone granite is medium gray in color, of pronounced schistose structure, and in texture varies from fine- to medium-grained. More or less tendency toward a poorly defined porphyritic texture is manifested in some parts of the area. The feldspars are partly of a pronounced pinkish hue, which impart a slightly mixed pink and gray color to the rock. In some respects hand specimens from the Raleigh and Greystone areas bear some resemblance to each other; in others they are strikingly different. In mineral composition they are essentially identical.

The principal minerals are quartz, orthoclase, microcline, microperthite, a little acid plagioclase near oligoclase, biotite, apatite, zircon, chlorite, muscovite, and kaolin. Microscopically the most noteworthy feature of the granite in this area is the very small amount of plagioclase present, which entirely fails in some of the thin sections. When present, the plagioclase individuals show broad twinning bands having extinction angles near that of oligoclase. Micro-

cline is a constant constituent, and, though somewhat variable, it may equal in amount the orthoclase. Intergrowths of orthoclase with a second feldspar as microperthite are fairly characteristic. Simultaneous crystallization of the quartz and a part of the feldspar is clearly indicated in micrographic intergrowths of the two minerals, and in the development of the micropoikilitic structure in the potash feldspars. The drop-like inclusions in the feldspar consist of quartz and other feldspar species, principally plagioclase. The feldspars are partially clouded from irregular patchy areas of alteration to minute scales of muscovite and kaolin. Carlsbad twinning is not uncommon among the feldspars. Biotite is in irregular shreds of brown color and strong pleochroism, and in many of the sections it is extensively altered to chlorite. Occasional shreds of muscovite are intergrown with the biotite. Zircon inclusions are somewhat common to the three principal constituents, feldspar, quartz, and biotite. The effects of dynamic forces are manifested in the thin sections by peripheral shattering and recrystallization, and in strained shadows in the principal minerals, quartz and feldspar. Megascopically the arrangement of the minerals along approximately parallel lines is manifested in the development of a thinly schistose structure.

The granite areas farther north in Warren county bear no resemblance in the hand specimens of the rocks to the Raleigh and Greystone granites, though they differ only slightly in mineralogy. In one exposure near Warren Plains biotite entirely fails, and muscovite is substituted. To the north of this locality biotite again assumes the rôle of principal accessory with some muscovite present, and the granite has abundant garnets scattered through it.

The granite of the Louisburg area in Franklin county resembles somewhat that of the Greystone quarries in the hand specimens, except that the former is entirely massive. Plagioclase occurs only sparingly in the granite of the Louisburg area, and microcline and microperthite entirely fail. In other essentials the granite from the two areas is similar. Over parts of the Louisburg area as well as at Greystone a slight porphyritic tendency is indicated in the rock.

THE MAIN GRANITE BELT.

GENERAL CHARACTERS.

This belt is an irregular one in width, occupying the central part of the Carolina Piedmont region, and extending from near the Virginia line in Person county, North Carolina, in a southwest direction across the state into Mecklenburg and Gaston counties, along the South Carolina line. The whole or a part of a dozen counties are included within the limits of this belt. Granite, either massive or schistose in structure, forms the principal rock type over the belt.

Texturally two distinct phases of the granite are developed, an even-granular and a porphyritic granite, both of which have wide distribution. With the single exception discussed on p. 381, the two texturally unlike rocks represent phases of the same granite mass. In all other essentials the normal and the porphyritic granites are closely similar.

Over many parts of the belt the granite manifests some evidence of the effects of intense dynamic forces, in many instances resulting in the partial or complete development of a secondary schistose structure. In thin sections of the rock from those areas in which the granite megascopically appears entirely massive, evidence more or less pronounced of pressure-metamorphism is shown.

The rocks are usually colored some shade of gray, light or dark, in accordance with the proportion of the ferromagnesian mineral present. In some a pronounced pink prevails, and the biotite, which is in very small amount, is not noticeable in the rock. Hardly without exception, the rocks are biotite granites, containing in several places additional hornblende, which is the principal accessory in the granite of several areas in Mecklenburg county, although biotite does not entirely fail in these. Muscovite as a primary constituent is sparingly developed, in a few localities, in association with biotite.

Microscopically the granites are essentially the same in mineral composition as those described above and to the east of this belt. Plagioclase feldspar is a nearly constant constituent, though subject to some variation. At times it exceeds the potash feldspar in amount, and it does not entirely fail in but one or two of the thin sections. Optically it corresponds to a very acid plagioclase, albite or oligoclase, or both. Orthoclase and microcline are both usually present

in the sections, oftentimes in nearly equal proportions, though the microcline is subject to considerable variation. Simultaneous crystallization of the quartz and a part of the feldspar is usually indicated in the distributed areas of micrographic intergrowths of the two minerals and in the development of micropoikilitic structure in some of the feldspars, the inclusions consisting largely of quartz and plagioclase. The usual accessory minerals common to granite are noted in the thin sections of the rocks.

The porphyritic granites have been previously described on p. 378, and it is only necessary here to again emphasize the fact that they are in every case biotite-bearing without hornblende, and are the equivalents in mineral composition of the even-granular granites. Three areas, representing different types of the normal granites, are separately described below. These are: the Dunn's Mountain area in Rowan county; the Mooresville area in Iredell county; and the occurrence of hornblende granite in Mecklenburg county to the north and the south of Charlotte.

LITHOLOGICAL CHARACTERS.

The Dunn's Mountain area.—This is a granite ridge twelve to fourteen miles long, having a general northeast-southwest trend and located a few miles southeast of Salisbury. Numerous quarries have been worked over many parts of the ridge which afford excellent opportunity for obtaining fresh specimens of the rock. Two distinct types of the rock are recognized; (*a*) a very light gray, nearly white, and (*b*) a pronounced pink. The two are intimately associated. They have the same mineral composition and texture, and are apparently phases or differently colored portions of the same rock-mass. The texture is medium even-granular and is fairly uniform. Dynamic metamorphism has manifested itself over all parts of the ridge in a faintly marked schistose structure, and on the Josey-Bogers places three miles southwest of the village of Faith the rock is completely thinly schistose. Over the north slope of Dunn's Mountain proper pronounced shear zones of the crushed and laminated rock, narrow in width, are developed in the granite mass, striking N. 55°–70° E. The rock surfaces are slickensided, accompanied by considerable epidotization.

The component minerals are quartz, orthoclase, microcline, at times microperthite, abundant plagioclase, a little biotite, magnetite, chlorite, epidote, titanite, rutile, and occasional garnet. The granite is largely a mixture of feldspar and quartz, with scant biotite as the third principal component. One of the most striking features in the mineral composition of the rock is its poverty in the ferromagnesian mineral and the excessive plagioclase, which latter constituent exceeds the potash feldspars in all the thin sections examined. Plagioclase is in large, stout, rudely prismatic forms, polysynthetically twinned, and corresponds in optical properties to albite and very acid oligoclase. Both orthoclase and microcline occur, the latter very variable in quantity, being reduced to one or two grains in some sections and in fairly good proportion in others. Microperthite is distributed in small amount through some of the sections. Carlsbad twinning is observed, but it is not so frequent as in some of the granites from other localities in the state. In the pink phase of the rock the feldspars are usually filled with closely crowded dust-like particles of a reddish-brown color, which probably represent some form of iron oxide. Biotite, when present in the thin sections, is of the usual kind, and is distributed through the rock in small, very irregular shreds, altered largely to chlorite. Quartz occupies well-defined areas between the larger feldspars, forming an aggregate of interlocking fine grains, in which feldspar may or may not appear.

Crushing and recrystallization from the action of intense dynamic forces are strongly emphasized in all of the thin sections. Finer mosaics of quartz and feldspar border the larger individuals of the two minerals and fill the interspaces. The larger laths of plagioclase are fractured and broken, and in many instances curved and bent, with irregular fractures and strained shadows common to the other essential components.

The Mooresville area.—The porphyritic granite of the Mooresville area has been previously described on pp. 380 and 381. Attention is here directed to the even-granular granite, which is a very fine textured rock of dark gray color. It is strongly contrasted with that of the Dunn's Mountain area described above. Orthoclase and microcline are in nearly equal amount. Unlike the other areas, plagioclase is very sparingly present, not more than a few grains

being observed in any one of the sections. Some microperthite occurs. Biotite of deep brown color and strong pleochroism is uniformly distributed in large amount through the sections, altered principally to chlorite, a colorless mica, and occasional epidote. Areas of micrographic structure are abundantly distributed through some of the sections, clearly indicating the overlapping of the periods of formation of the quartz and feldspar. Pleochroic titanite in crystals and grains is quite freely developed in one of the sections. Inclusions of apatite and zircon are fairly constant.

The Mecklenburg county areas.—Biotite-bearing hornblende granite occurs one mile east of Davidson in the extreme northern part of the county, and again five to six miles south of Charlotte in the extreme southern part of the county. Hand specimens of these granites are entirely different from, and bear no resemblance whatever to, those of the types previously described. They are of medium texture and gray color, and in the locality south of Charlotte a few bowlders have been worked off for monuments. Much plagioclase is present in association with the potash feldspar. Compact hornblende with strong cleavage development is the principal ferromagnesian mineral present. It is accompanied by more or less biotite of the usual kind, which varies greatly in amount.

The granite to the east of Davidson contains large lath-shaped crystals of the hornblende distributed through it, which measure in extreme cases as much as one and a half inches in length. All gradations in the size of the hornblende individuals down to the smallest grains occur. Chlorite is one of the chief alteration products of the ferromagnesian constituent. Much titaniferous magnetite occurs along with some of the usual minor accessories.

THE WESTERN PIEDMONT GNEISS AND GRANITE BELT.

GENERAL CHARACTERS.

The principal rocks of this belt are gneisses of variable mineral composition. A residual of biotite granite-gneiss, closely resembling in the hand specimens and in mineral composition the well-known Lithonia area of granite-gneiss in Georgia,[1] occurs in Alexander

[1] "Granites and Gneisses of Georgia," *Bulletin No. 9-A*, Geological Survey of Georgia, 1902, pp. 125 ff.

county near Hiddenite. Large areas of biotite granite of medium to coarse texture are located in the northern part of the belt. The Mount Airy area in Surry county, near the Virginia line, may be taken as the type.

LITHOLOGICAL CHARACTERS.

The Mount Airy granite area.—Quarries are worked one and a half miles north of the town of Mount Airy, on a ridge slope of continuously exposed granite. In mineral composition the Mount Airy granite does not differ essentially from some of the types already described, though hand specimens of the rock bear little or no resemblance to each other. The usual granitic minerals are noted, such as quartz, orthoclase, microcline, plagioclase, biotite, muscovite, zircon, apatite, epidote, chlorite, and magnetite. In addition to these, several grains of allanite have been noted in one of the thin sections. Orthoclase is in excess of the microline in all of the sections examined, accompanied by a larger proportion of finely striated acid plagioclase. Zonal growth and Carlsbad twins are beautifully developed in some of the feldspars. Biotite of brown color and strong pleochroism is the principal accessory, and is altered into chlorite, a colorless mica, and some epidote. Much secondary muscovite derived from the alteration of the feldspar and biotite is present. The large individuals of quartz and feldspar indicate peripheral shattering in finer-grained mosaics of the two minerals filling the interstices.

GRANITES OF THE APPALACHIAN MOUNTAIN REGION.

GENERAL CHARACTERS.

Areas of granite and granite-gneiss resembling essentially in mineral composition some of the granite types described above are known over parts of the mountain region of the state. Those of the extreme northwest part of the state have recently been mapped and described by Keith.[1] Since, with perhaps a single exception, those of the other parts of the mountain region are not unlike certain types already described in this paper, only one type is of special interest here, namely, unakite, which occurs in the vicinity of Hot Springs,

[1] *Geologic Atlas of the United States*, "Cranberry Folio, North Carolina–Tennessee." U. S. Geological Survey, 1903.

Madison county, North Carolina, and the contiguous part of Cocke county, Tennessee.

LITHOLOGICAL CHARACTERS.

The Unakite area.—The unakite area in Madison county, North Carolina, and Cocke county, Tennessee, is the type locality first described by Bradley in 1874. I quote in full Bradley's description:[1]

> This name [Unakite] is proposed for a member of the granitic series, from the Great Smoky Mountains, a portion of the Unaka range of the Blue Ridge, which range forms the boundary between Tennessee and North Carolina. The specimens thus far seen are from the slopes of the peaks known as "The Bluff," "Walnut Mountain," and "Max's Patch," Cocke county, Tenn., and Madison county, N. C. The rock is said to occur also in Yancey county, N. C., but in a comparatively inaccessible region.
>
> The character relied upon for the separation of the species is the constant replacement of the *mica* of common granite, or the *hornblende* of syenite, by epidote. The amount of this ingredient present is quite variable, in some cases even exceeding one-half of the whole mass. The feldspar present is orthoclase, of various shades of pink, forming from one-fourth to perhaps one-third of the whole. The quartz is mainly white, but occasionally smoky; its isolated portions form but a small part, say one-fourth, of the mass; it is veined in structure, but this is probably not a constant character. Small grains of magnetite are scattered through the rock, but not so thickly as in many granites. No other ingredients have as yet been detected. Mr. G. W. Hawes has determined the specific gravity at 2.79. The rock is very compact and takes a high polish, and will doubtless prove to be a valuable material for ornamental architecture.
>
> The deep weathering of all the rocks of the Southern Appalachians has caused the covering of most of these mountain slopes with deep beds of débris, which conceal most of the solid outcrops; and the dimensions of the bodies of uanakyte are therefore as yet unknown. Apparently forming part of the same series, there are heavy beds of specular iron ore; and the whole series is referred with little doubt to Archaean age.

The outcrops of the granite over the surface, as traversed by me, indicate an area of about twenty-four square miles, lying mostly in Madison county, North Carolina, beginning about five miles southwest of Hot Springs. Further detailed work will probably extend the boundaries of the area considerably beyond those mentioned here.

Two types of the granite occur in the area, both of which contain epidote. The bulk of the granite or main body of the rock is a dark

[1] *American Journal of Science*, Vol. CVII (1874), pp. 519, 520.

pinkish-green epidote granite of medium-coarse texture and fairly schistose or foliated in structure. This is not the unakite proper, but may be properly designated the epidote-bearing rock. It varies from a typical granite in which quartz is present in the usual amount to a nearly quartzless rock of the same color and texture. The unakite proper is a coarse-textured rock composed of yellow-green epidote, dull pink or red feldspar, and quartz. It is not entirely uniform in color and composition, but it grades into a highly feldspathic rock of pink color on the one hand, and an epidotic rock of yellowish-green color on the other, with still a third gradation observed into pure quartz.

Thin sections of the epidote-bearing granite show the principal minerals, quartz, orthoclase, and microcline, in about equal proportion, a little plagioclase, biotite, epidote, chlorite, rutile, zircon, apatite, magnetite, pyrite, and kaolin. The epidote distributed through the sections is wholly a secondary product derived from the interaction of the biotite and feldspar. It occurs in the form of minute microscopic granules thickly crowded together, in many cases lying next to the biotite. The mass of granules, when forming an area large enough to be visible megascopically, appears as a single large epidote individual rather than as separate microscopic granules. Besides epidote, the feldspars are altered to a colorless mica, and in some instances the original mineral is completely obscured by the alteration products. At times the feldspars are much fractured and broken, the fissures of which are now filled with another mineral substance. Sometimes alteration has progressed along the lines of fracture in the feldspar, and patches and stringers of deep-green mica line them. Thread-like filaments of rutile, broken into minute segments, are crowded together in the quartz anhedra. Some peripheral shattering from pressure-metamorphism is indicated in narrow zones of fine-grained mosaics of quartz and feldspar partially surrounding these two minerals. Strained shadows and fractures are common to both the larger quartz and feldspar grains.

The principal difference microscopically between the unakite and the epidote-bearing rock is that of extreme epidotization of the former, further marked by the absence, in those sections studied, of both plagioclase and ferromagnesian minerals, identified as such.

Since both of these minerals are present in the epidote-bearing rock, their absence in the unakite is very likely due to extreme epidotization of the unakite, completely altering both the mica and the plagioclase in case these were originally present. That mica or some ferromagnesian constituent was originally present in the unakite it seems necessary to assume in order to meet the requisite conditions of formation of so large a quantity of epidote.

The principal component minerals in the unakite are quartz, orthoclase, epidote, rutile, titaniferous iron oxide, and secondary muscovite, kaolin, and leucoxene. Rutile is contained in the quartz anhedra as inclusions of hair-like filaments. The orthoclase has a pronounced pink color in the hand specimens which disappears in the thin sections. Here, as in the epidote-bearing rock, conclusive evidence is furnished of the wholly secondary nature of the epidote. Its largest occurrence is in the replacement of the feldspar individuals in the form of a complete mass of microscopic granules, entirely obscuring in many cases the feldspar substance, but preserving the outline of the latter in a more or less perfect manner. The granular masses of epidote appear in the hand specimens as single large epidote anhedra. Other feldspar individuals show patchy areas and scattered granules of epidote over their surfaces. Still a third occurrence of the epidote is in irregular broken bands or stringers, following the network of fractures in both the feldspar and the quartz. In some cases these stringers ramify outward from the granular masses of epidote, replacing the feldspar. Again the granular masses often show irregular margins traced outward from the more compact mass into scattered granules of epidote. All gradations between these occurrences of the epidote are traced. Very little of the feldspar is entirely free from epidotization.

Some peripheral shattering accompanied by much fracturing of, and strained shadows in, the quartz and feldspar, indicating the effects of dynamic forces, characterizes to some degree all of the thin sections.

It seemed quite conclusive, from the different exposures studied of the unakite in its relations to the inclosing epidote-bearing granite, that the unakite is of distinct vein character which can be referred

very likely to the segregation type.[1] It does not exist in quantity large enough to be worked over any part of the area traversed by me; hence it has only scientific interest.

STRUCTURAL FEATURES OF THE GRANITES.

MEGASCOPIC STRUCTURES.

Joints.—With possibly one or two exceptions, the Carolina granites are characterized by a strong development of the jointed structure, the planes of which break the rock into polygonal blocks of different sizes, as indicated in Fig. 4. The most noteworthy exception is that of the extensive granite area near Mount Airy, in which no visible jointing is apparent. Careful measurements of the joint-planes were made in all the granite openings visited in the state, and the results can be summarized as follows: Those joints whose planes lie in the northeast and the northwest quadrants respectively, and composing the major jointing; and two minor sets whose planes strike east-west and north-south. In the northeast and the northwest quadrants the limits of variation in the strike of the joint-planes are N. 10° E. or W., to N. 80° E. or W. Out of the total number of joint-planes measured fifty-six lie in the northeast quadrant and forty-five in the northwest quadrant; while nineteen strike in a north-south direction, as against sixteen having an east-west strike.

Slickensides.—As a rule, the joint-planes show smooth, more or less polished and striated surfaces, indicating considerable movement in the rocks since the formation of the joints. Striæ are developed in a thin coating of yellow to yellowish-green mineral substance, derived from certain minerals in the granite and produced by the rubbing together of the two sides along the plane.

Schistosity.—Between the perfectly schistose granites (granite-gneisses) and the perfectly massive granites, nearly all gradations in

[1] Since this paper was written, PHALEN ("A New Occurrence of Unakite," *Smithsonian Miscellaneous Collections*, Vol. XLV (1904), pp. 306–16) has published a preliminary paper on the occurrence and petrography of unakite at Milams Gap in Virginia. The rock in which the unakite occurs in the Virginia locality is reported by the author to be hypersthene akerite. The epidote of the unakite is secondary, replacing pyroxene and feldspar, both plagioclase and orthoclase. The author believes the unakite has originated from the akerite by hydrometamorphism, aided perhaps by dynamic disturbances.

schistose structure are shown. Not in the same mass, however; for not in a single instance has such been observed. Whether the entirely schistose structure is more or less sharply and completely separated from the massive, or whether they grade from one into the other, it is impossible to say, owing largely to the lack of sufficient exposures of the rocks. Even in most of those granites which megascopically

FIG. 4.—Vertical jointing in granite. City of Charlotte quarry, North Carolina.

appear massive, more or less evidence is shown in the thin sections of the effects of dynamic forces, in peripheral shattering or granulation, and in strained shadows and fractures in the quartz and the feldspar. In such cases no semblance of rearrangement of the mineral components along certain definite lines appears.

Basic inclusions.—The granite in many of the quarries contains inclusions of basic segregations which were formed from the cooling magma. These are invariably of darker color and finer grain than the inclosing granite, and are entirely massive. Sections from them resemble closely the inclosing granites in mineral composition, except

that biotite is greatly in excess, while quartz may be somewhat diminished in quantity. It frequently requires the closest examination, megascopically, to detect more of the minerals than the dark ferromagnesian components, except in a few cases where an occasional porphyritically developed feldspar has formed, so fine-grained and very dark in color are the schlieren.

Their distribution in the granites is subject to much variation. From some quarries they are entirely absent, in others they are developed only occasionally, and in others still they are so abundant as to exclude the rock from use in certain higher grades of work. Variation in size is from a fraction of an inch to more than a dozen inches across. Irregularity of outline is usually characteristic of them, variation being from roughly oval-shaped and round to greatly elongated areas, one of whose diameters is several times that of the second.

MICROSCOPIC STRUCTURES.

Peripheral shattering or granulation and recrystallization has already been mentioned. It is only necessary here to call attention briefly to two fairly constant microstructures in the granites, observed in similar rocks elsewhere, namely, granophyric and micropoikilitic.

Granophyric structure.—Granophyric intergrowths of feldspar and quartz are either sparingly or abundantly developed in most of the thin sections examined of the Carolina granites. They display the usual form and development observed in granites in general. So far as it was possible to determine, the intergrown feldspar may be either of the potash or plagioclase species. The areas may be inclosed by the larger feldspar individuals, or they may be formed at or near the contact between the larger feldspar and quartz grains. Their character clearly indicates simultaneous crystallization of the two minerals—an overlapping in the period of formation of the feldspar and quartz. This conclusion finds added confirmation in the micropoikilitic structure described next below.

Micropoikilitic structure.[1]—In thin sections of the granites from both North Carolina and Georgia, certain of the large feldspar

[1] G. H. WILLIAMS, "On the Use of the Terms Poikilitic and Micropoikilitic in Petrography," JOURNAL OF GEOLOGY, Vol. I (1893), pp. 179 ff. This paper contains numerous references to published accounts of this structure.

individuals are frequently filled with crystals, or grains of other minerals, arranged without reference to one another or to their host. Hardly without exception, the inclosing mineral is a potash feldspar, and the included minerals are quartz and plagioclase, with an occasional shred of biotite. In the phenocrysts of the porphyritic granites this order is frequently reversed, and biotite is often inclosed in largest amount. Variation is from several scattered included grains in the feldspar to hosts fairly filled with the inclusions. The inclosed quartz grains are rounded in outline, drop-like in form, while the striated plagioclase may vary from similarly rounded grains to lath-shaped forms.

Because of its occurrence in devitrified glasses, Williams[1] ascribed in some cases a secondary origin to the very abundant micropoikilitic structure in the ancient acid lavas of South Mountain, Pennsylvania, and Maryland. There is no evidence for regarding the structure in the Carolina and Georgia granites of other than primary origin—a fact which aids, as I interpret it, in formulating the order of separation of the feldspars and quartz from the magma. When viewed in connection with the granophyric structure described above, the two microstructures furnish conclusive evidence of the overlapping in the period of crystallization in the potash and plagioclase feldspars and the quartz in the southern granites. A tendency was noted in many of these sections toward maximum development of the two structures in the same thin section. This seeming association was by no means a constant feature, for many sections in which granophyric intergrowths were present indicated the entire absence of the micropoikilitic structure.

INTERSECTING DIKES AND VEINS.

Genetically the intersecting materials are of two kinds, true dikes and true veins. These contrast quite strongly in some instances, and in all cases they show differences to some degree in both texture and composition.

BASIC IGNEOUS DIKES.

Dikes of basic igneous rocks, principally diabase or its altered form, were observed penetrating the granites in most of the important areas in the state. A majority of these were noted from surface

[1] G. H. WILLIAMS, *American Journal of Science*, Vol. XLIV (1892, 3d S.), p. 482.

exposures of the rocks, and hence more or less deeply decayed, while many of them were exposed in the quarry openings, which afford excellent opportunity for observing their relations to certain structural features of the granite discussed below (Fig. 5). In several quarries in widely separated parts of the state a series of some half-dozen or more dikes were observed. Where exposed in the quarries,

FIG. 5.—Dike of diabase penetrating granite in the city of Charlotte granite quarry, North Carolina. Part of a second dike is visible in the extreme left of the view.

none of the dikes exceed fifty feet across, and usually they are less than four feet.

Lithologically two types are indicated. The first is usually an unaltered massive diabase, the thin sections of which show under the microscope the essential minerals and structure of diabase. The pyroxene in this type may be considerably altered in some of the dikes, and in hand specimens the rock presents a rather pronounced greenish hue, resulting from the alteration. The second type is more or less completely thinly schistose, and is largely composed of horn-

blende, some feldspar and quartz, and may contain much additional pyrite. The rock is a typical amphibolite derived from an original diabase or diorite or both.

The structural relations of the dikes to each other and to the inclosing granites clearly indicate at least two different periods of penetration of the granites by the basic rocks, and therefore different ages for the dikes. More or less complete evidence of schistose structure in the inclosing granites is sometimes noted in those cases where cut by dikes of similar structure. I take it that the period of intrusion of the dike antedates that of the dynamic disturbance inducing schistosity into both dike and granite alike. In those cases where the dike rock remains massive and the inclosing granite shows evidence of schistose structure, the reasonable conclusion is that the basic dike material penetrated the granite after the period of dynamic disturbance closed.

GRANITE DIKES

True granite dikes of normal composition and usually fine texture are numerous in certain areas, but only in one or two instances have they been observed penetrating the granite masses. In the main granite belt of the Piedmont region dikes of this character are quite frequent, penetrating the surrounding rocks, and they must be regarded as apophyses from the granite massifs (Fig. 6). As a rule, they vary only a few degrees from the vertical; are irregular in outline; fine-grained in texture; composed of light to pink feldspar and quartz, with subordinate amount of mica, which may entirely fail at times; and they range from a few inches to several feet in width.

PEGMATITE AND APLITE.

Pegmatites are present in large numbers in some quarries and entirely fail in others. As a rule, they do not attain very large size, but are narrow, apparently deep-seated, and of aqueo-igneous origin. Others are limited in extent, surrounded entirely by the granite, marking in such cases true veins of segregation. Texture and composition of the two are identical. They are chracterized by the usual coarse crystallizations of feldspar and quartz, with subordinate stout, platy, black biotite. The feldspar may be pink or white, showing

good cleavage development, and twinning on the Carlsbad law. Feldspar is the most abundant constituent, composed of microcline and orthoclase, with little plagioclase; quartz frequently occurring in very small amount. Muscovite has been observed occasionally; and tourmaline, garnet, and the rarer minerals sometimes associated with pegmatites, are strikingly absent.

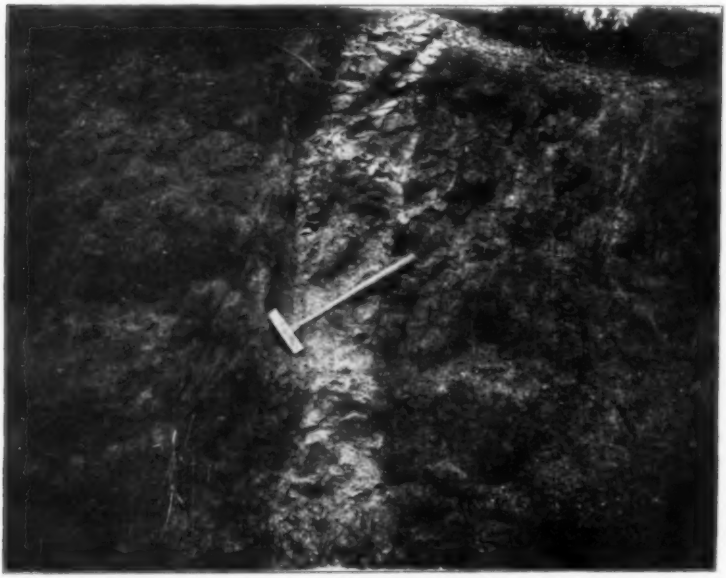

FIG. 6.—Granite dike west of Salisbury, North Carolina.

In the Raleigh city quarries where the only true aplite has been observed, the aplite and pegmatite are associated as banded aplite-pegmatite, the aplite being in contact with the pegmatite on one side and the inclosing granite on the other. They are very light-colored rocks, containing but little biotite; are fine-grained; and are only a few inches across. Orthoclase, microcline, very little plagioclase, microperthite, quartz, biotite, muscovite, chlorite, rutile, magnetite, and kaolin appear in thin section. Microscopically they are potash aplites.

QUARTZ VEINS.

Quartz veins of small dimensions cut the granite in a number of quarries; usually, in the ones where pegmatitic intrusions are strongly developed. They are not numerous in any of the openings, and, as a rule, they will not measure more than a few inches across. Veins of quartz of considerable dimensions are numerous over the crystalline

FIG. 7.—Stone Mountain, Wilkes county, North Carolina. A granite residual. Several others are shown in the distance on the extreme left of the view.

area of the state, and they can be readily traced over the surface for considerable distances by partially disintegrated outcrops and abundant angular fragments which litter the surface.

RELATIONS BETWEEN THE JOINTS IN THE GRANITE AND THE DIKES OF BASIC ROCK.

Referring to the direction in the strike of joints discussed on p. 23, it will be observed that the planes of most of the joints lie in the northeast and the northwest quadrants, respectively. Likewise careful measurement and tabulation of the dikes of basic rocks show that the

direction of strike of most of them is in the same quadrants as the strike of the joints. Furthermore, in nearly every quarry exposing dikes of basic igneous rocks the strike of the dikes and that of one set of joints were coincident, probably indicating that for the areas mentioned the jointing has exercised some influence in the cutting direction of the dikes.

Not only is this true of the dikes penetrating the granites, but it is equally true of the Triassic sandstone belt, where coincidence in strike of the diabase dikes and that of jointing in the sandstone is very strikingly shown.

Careful measurements in the strike of the joints and the dikes were made in the numerous openings over the sandstone belt, which can be summarized as follows:[1] Variation in major jointing is from N.15°–60° W. to N. 20°–60° E., with minor sets noted in some openings striking N.-S. and E.-W. Likewise, variation in strike of the dikes is from N. 20°–60° W. to N. 20° E., with a few striking N.-S. In every opening the strike of the dikes and that of the joints for a given direction was found to be coincident.

Whether this will apply in general to those dikes beyond the limits of the fresh rock exposures it is not possible to say at present, as the jointing is entirely obscured by the deep residual decay covering the fresh rocks.

AGE-RELATIONS OF THE DIKES OF BASIC IGNEOUS ROCKS.

As noted above in the basic dikes penetrating the crystalline rocks, strongly contrasted structural differences in the dike rocks obtain. Many of them are entirely massive and unaltered, bearing little or no evidence of pressure-metamorphism, while a large proportion of them are completely schistose, and are otherwise mashed and closely jointed. The ferromagnesian constituent in the latter is usually partially or completely altered. Both classes of the dikes often penetrate original massive igneous rocks that are now more or less schistose in structure. These facts afford a strong and sufficient basis for regarding the basic rocks of the dikes of different periods of intrusion, and therefore, of different age. The massive dikes penetrating the more or less schistose rocks must postdate in age the period of

[1] Data kindly furnished by Mr. F. B. Laney.

disturbance inducing the schistose structure in the inclosing rocks. Likewise the schistose dikes were intruded at an earlier period and prior to the metamorphism of the inclosing rocks, for the field evidence indicates that the schistose structure in the dike and the inclosing rock is the result of the same forces. Until the age of the inclosing rocks is definitely determined, that of the more schistose dikes must largely remain conjectural. As stated, the dikes must antedate the period of pressure-metamorphism affecting the inclosing rocks, for both dike and inclosing rock are similarly affected.

The sandstones of Triassic age occupying the marginal position along the eastern border of the Piedmont region, are cut by a system of typical massive, unaltered, diabase dikes. The dikes conform, as a rule, to northeast and northwest directions, and are coincident in strike with that of the joints in the sandstones for these directions. Nowhere have the dikes been observed to cut rocks younger than the sandstone, and their age is accordingly definitely fixed as middle Mesozoic. They are correlated with flows of the same composition and age in New Jersey, New York, and the Connecticut Valley region, and with similar dikes in Virginia and Georgia to the north and south of the Carolina area.

The dikes of the Carolina sandstone belt are traced into the neighboring crystalline rocks of the Plateau region, where they have wide distribution. Beyond the limits of the sandstone belt, in the crystalline areas penetrated by the dikes, close similarity in texture, structure, and composition of the massive dikes obtains, and their relations to the inclosing crystalline rocks make it reasonably certain that they are of the same age as those penetrating the Triassic sandstones.

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GEOLOGICAL NOTES ON THE VICINITY OF BANFF, ALBERTA.

BANFF, the easternmost of the resorts established by the Canadian Pacific Railroad in the mountains of the Northwest, lies a little east of the axis of the Rocky Mountain range, on the Bow River, at an altitude of 4,521 feet. The surrounding mountains rise to heights of 8,000 to 10,000 feet and upward.

Structure of the mountains.—The Rocky Mountains in Alberta contrast with the same range in the United States in that folding and overthrust faulting are their predominant features. Their structure closely resembles that of the southern Appalachians, contrasting strongly with the Basin type where normal faulting is the rule.

In Alberta parallel ridges of folded Carbonic limestones are the prevailing features. These are underlain by Cambrian sandstones, and overlain by coal-bearing Cretaceous sandstones. About Banff the general trend of the ridges is northwest-southeast.

Drainage.—The normal drainage of the region is similar to that often noted in the Appalachian region; the channels being established either along the strike of some soft layer, or cutting across the ridges at right angles to the strike. In such a region stream robbery is common, and one river will, at an advanced stage of adjustment, present a series of right-angled turns, wind-gaps often indicating former channels.

Glaciation.—The Canadian Rockies have been heavily glaciated at a comparatively recent date. The glacial action appears to have been that of very large valley glaciers, rather than of the continental ice-sheet. Local moraines are common, and the larger valleys are bordered by glacial terraces.

The drainage in the vicinity of Banff presents several interesting features. The Bow River, after flowing southwest along the strike of the Cambrian sandstones, turns abruptly northeast, cutting a gap in the Sawback, Vermilion, and Cascade ranges (see map, Fig. 1). It then turns southeast again, flowing along the strike of a Cretaceous

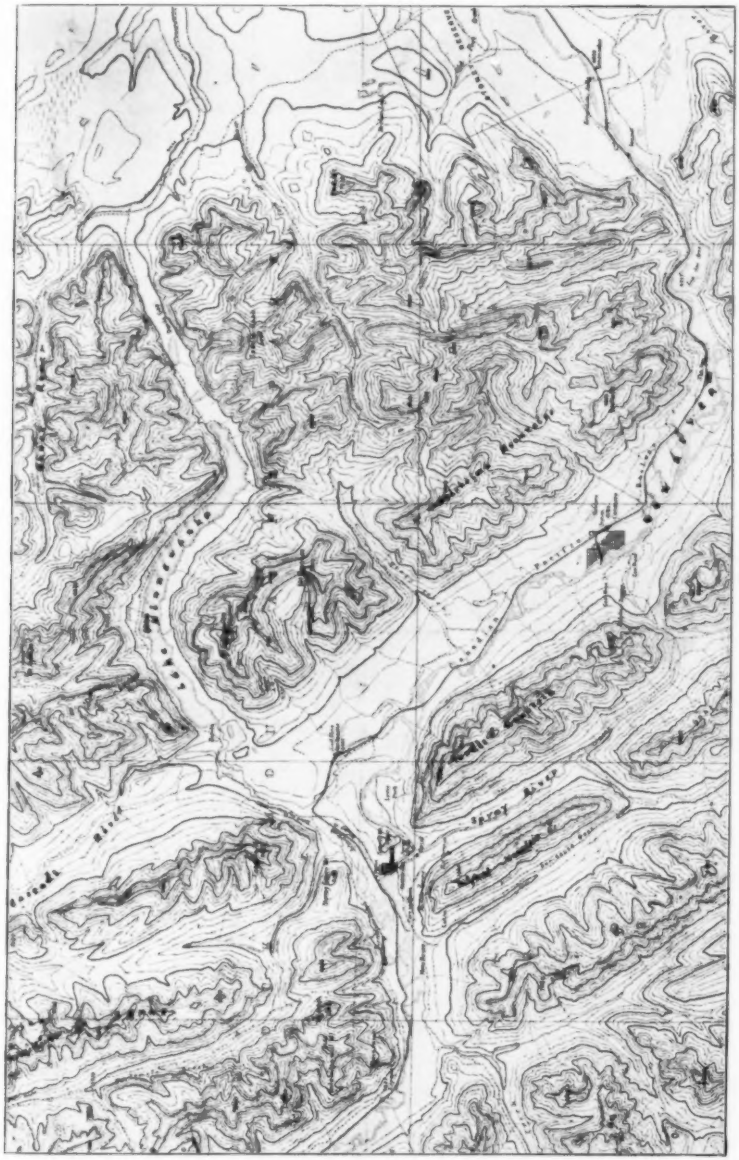

FIG. 1.—Topographic map of the Rocky Mountains near Banff. Reduced from Canadian Geological Survey.

infold. At Banff the Bow River is joined by the Spray River from the southeast and by the Cascade River from the northwest. Lake Minnewauka outlets westward into the Cascade River, its eastern end leading through a wind-gap to the Ghost River.

The Bow Valley about Banff is drift-filled. Westward from the station its course is through gravel, largely stratified (Fig. 2). At the

FIG. 2.—Still waters and alluvial deposits of the Upper Bow River above Banff; Mount Edith in the distance.

station the river turns abruptly southeast, cutting a little canyon along the strike of Carbonic shale and forming the Bow Falls. At its junction with the Spray it again enters drift and again turns northeast. There is here presented the abnormal feature of a water-fall along the strike, followed by quiet water when the course is at right angles to strike and up dip.

Forty-mile Creek flows southeast along the strike between Vermilion and Sawback ranges. It cuts across a gap in Vermilion

range and cuts off the end of Cascade Mountain. As it enters the Bow Valley it turns abruptly west, flowing over drift for a mile and a half, and emptying into Vermilion Lake.

These various abnormalities are the result of two distinct causes: first, adjustment to the soft Cretaceous infold of the lower Bow Valley; second, glaciation.

FIG. 3.—Devil's Canyon; a postglacial gorge of the Cascade River.

Lake Minnewauka (Devil's Lake) is a body of water twelve miles long and about half a mile wide. Its sides are precipitous, except close to the water's edge where glacial gravels are found. Alluvial cones occur, projecting into the lake. As noted by Dawson in 1885,[1] this lake basin presents every appearance of having formerly been a river valley. Its eastern end is now filled with drift, talus, and alluvial cones, but its level floor and steep sides extend to Ghost River on the east. Dawson, in the report cited, suggests that this was the

[1] *Report B*, Geological Survey of Canada, 1885, p. 141.

preglacial course of the Bow River. If this were the case, a drift-dam, or indications of an ice-dam, should be found, and the valley beneath the drift should present older features in the preglacial than in the present Bow Valley.

An investigation of the western end of the Lake Minnewauka disclosed hills of morainic aspect, evidently deposited at the junction of an ice-lobe descending the Cascade Valley with one coming from the Minnewauka Valley. Westward from these morainic hills is an overwash plain which descends westward and southeastward to form the upper terrace of the Cascade River. Lake Minnewauka is held up by this moraine, and its existence as a lake undoubtedly dates from the time of retreat of the ice. But that this dam could have diverted the Bow River is not possible. The outlet of Lake Minnewauka flows through drift for about a mile; it then joins the Cascade River, and together they flow through a postglacial gorge cut in Carbonic limestone. This gorge is known as the Devil's Canyon. The surface of this limestone is drift-covered, and the top of the gorge undoubtedly represents the height of the valley floor before the ice-invasion, also the amount eroded by the ice. This level is 5,000 feet. The limestone cut by the Devil's Canyon extends in a low ridge for more than a mile and blocks any considerable outlet or inlet of the Minnewauka Valley. Any river flowing in or out of this valley in preglacial times must have had its floor above 5,000 feet.

Five miles southwest of the lake the Bow River flows mainly over gravel. The Cretaceous beds are occasionally exposed, but the valley bottom is mainly in drift. The valley floor at this point is 4,350 feet, and the preglacial river in this valley could not have been higher. It therefore follows that no preglacial river could have flowed from the Bow to Lake Minnewauka Valley.

Moreover the lower Bow Valley (below the junction with Cascade River) is older physiographically than the Lake Minnewauka Valley. The sides are less precipitous, the cross-section, though steep sided, more nearly U-shaped.

In the opinion of the writer, the present drainage at this point is due, not to glacial agencies alone, but to preglacial adjustment to the soft Cretaceous beds. The Minnewauka Valley and the Bow Valley above the junction with Cascade River were probably once

one valley. Stream robbery then took place, owing to the advantage possessed by the present lower course of the Bow, a stream on the Cretaceous beds, over the upper part, the upper Bow-Minnewauka River. This adjustment was preglacial. The Bow was thus drawn away into its southeastward course in preglacial time, and a divide was established at the western end of Minnewauka Valley. A river

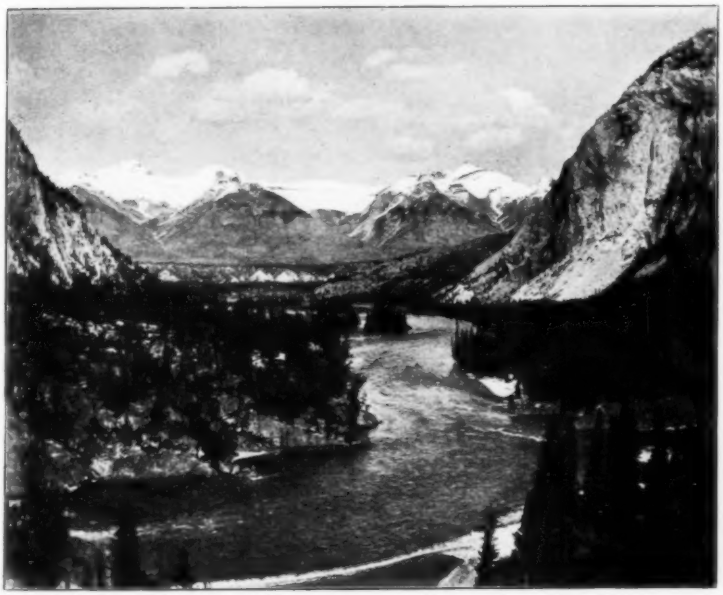

FIG. 4.—Bow Valley, from the Banff Springs Hotel; the preglacial course of the Spray River. At the left the Bow is emerging from its postglacial canyon.

continued to occupy this valley, emptying into Ghost River, until obliterated by the ice-invasion. The basin may have been deepened by ice-gouging; at all events, as the ice retreated northward, a lake was formed at its western margin, and an outlet was formed to the west, the eastern end of the gorge being still ice-filled. By the time the ice had retreated altogether, the westward outlet was too well established for a return to the eastward drainage. The present level of the lake is lower than that of Ghost River.

The abnormalities in the vicinity of Banff village appear to be due to glacial agencies only. Forty-mile Creek takes its abrupt westward bend at the point where its old valley is filled by drift. The Bow takes its southward turn around Tunnel Mountain for the same reason, namely, damming of its old valley by drift, its present rapids and fall being postglacial. South of Tunnel Mountain the Bow leaves its gorge and turns into the preglacial valley of the Spray (Fig. 4). The Spray itself has been pushed out of its valley at this point by talus from Mount Rundle.

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GLACIAL AND POST-GLACIAL HISTORY OF THE HUDSON AND CHAMPLAIN VALLEYS.

OUTLINE.

INTRODUCTORY STATEMENT.

TOPOGRAPHY OF EASTERN NEW YORK AND SOUTHERN NEW ENGLAND.

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HUDSON VALLEY SOUTH OF HIGHLANDS AND LOWLAND WEST OF PALISADE RIDGE.

- Brooklyn-Perth Amboy Moraine.
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- Drift of lowland west of Palisade Ridge and inside above moraine.
- Drift in the Hudson Valley south of Highlands and north of Long and Staten Islands.
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  - North Haverstraw.
  - Croton.
  - Oscawanna-Crugers-Peekskill.
  - Jones Point and State Camp.
  - Roye Hook.

HIGHLANDS OF THE HUDSON.

- Drift of the Highlands.

HUDSON VALLEY NORTH OF THE HIGHLANDS.

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- High-level terrace north of Fishkill.
- Drift at Carthage Landing, Low Point, and Roseton.
- New Hamburg gravel plateau and Wappinger Creek stratified drift.
- Camelot kames.
- Drift north of Camelot to north of Catskill.
- Drift north of Catskill to north of Glens Falls.
  - Old lake-floor or old sea-floor.
  - Gravel plateaus and deltas.
  - Elevations above old lake-floor or old sea-floor.
  - Depressions below old lake-floor or old sea-floor.
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- Submerged channel of the Hudson.
  - Extra-morainic channel.
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Wave-wrought features in the Hudson Valley.
Fossils in the Hudson Valley and in the lowland west of the Palisade Ridge.
Buried soils.
WESTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.
EASTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.
CHAMPLAIN VALLEY.
East side, Lake Champlain.
West side, Lake Champlain.
Clay plain.
Gravel plateaus and deltas—upper and lower series.
Wave-wrought terraces.
Upper series.
Lower series.
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Moraines.
Eskers.
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Fort Edward Valley.
Whitehall-Putnam Station Valley
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Erosion of tributaries to Poultney-Mettawee stream in southern Champlain region.

[*Outline to be concluded.*]

INTRODUCTORY STATEMENT.[1]

THE plans for the investigation the results of which are here presented were first made under the direction of Professor R. D. Salisbury. At the beginning of the actual work, in the absence of Professor Salisbury from the country, the work was pursued under the direction of Professor T. C. Chamberlin, and has been continued under his direction up to the present time. The writer's interest in the subject was first aroused while engaged in detailed mapping of the Pleistocene deposits of the Palisade Ridge of eastern New Jersey in 1893 and 1894, under Professor Salisbury's direction.[2] Subsequently, in the preparation of the Pleistocene maps for the *New York City Folio*[3]

[1] A brief summary of this paper was presented before the Geographic Society of Chicago in March, 1904. An alternative hypothesis bearing on crustal movement entertained at that time has replaced one favored then.

[2] See ROLLIN D. SALISBURY AND CHARLES E. PEET, "Drift Phenomena of the Palisade Ridge," *Annual Report of the State Geologist of New Jersey*, 1893.

[3] See Pleistocene maps of the *New York City Folio, U. S. Geological Survey*, by ROLLIN D. SALISBURY, assisted by HENRY B. KUMMEL AND CHARLES E. PEET.

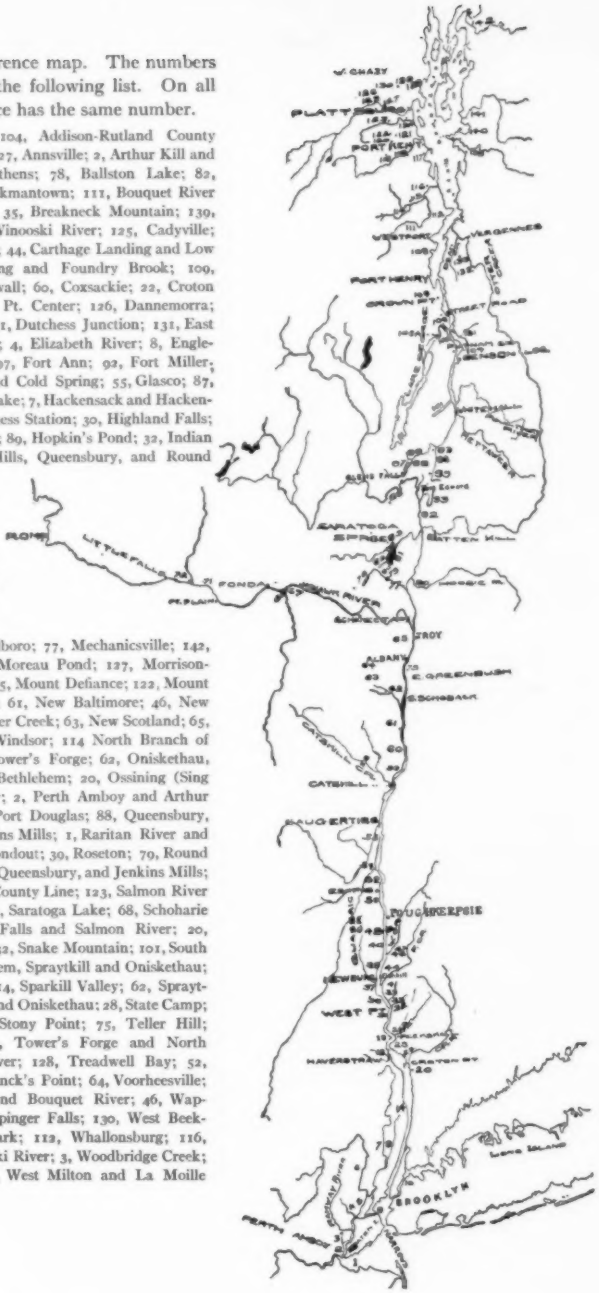

FIG. 1.—Reference map. The numbers refer to places in the following list. On all the maps each place has the same number.

133, Addison; 104, Addison-Rutland County Line; 67, Amsterdam; 27, Annsville; 2, Arthur Kill and Perth Amboy; 59, Athens; 78, Ballston Lake; 82, Ballston Spa; 129, Beekmantown; 111, Bouquet River and Wadham's Mills; 35, Breakneck Mountain; 139, Burlington and the Winooski River; 125, Cadyville; 58, Cairo; 48, Camelot; 44, Carthage Landing and Low Point; 33, Cold Spring and Foundry Brook; 109, Cole's Bay; 36, Cornwall; 60, Coxsackie; 22, Croton Landing; 108, Crown Pt. Center; 126, Dannemorra; 95, Dunham's Basin; 41, Dutchess Junction; 131, East Creek; 10, East River; 4, Elizabeth River; 8, Englewood; 119, Ferrona; 97, Fort Ann; 92, Fort Miller; 33, Foundry Brook and Cold Spring; 55, Glasco; 87, Glen Brook and Glen Lake; 7, Hackensack and Hackensack River; 120, Harkness Station; 30, Highland Falls; 90, Hoosic River delta; 89, Hopkin's Pond; 32, Indian Brook; 88, Jenkins Mills, Queensbury, and Round Pond; 19, Jones' Point; 118, Keeseville; 9, Kill van Kull; 141, La Moille River and West Milton; 83, Lonely Lake; 44, Low Point and Carthage Landing; 140, Mallett's Bay; 80, Maltaville; 40 Marlboro; 77, Mechanicsville; 142, Missisquoi River; 85, Moreau Pond; 127, Morrisonville; 93, Moses Kill; 105, Mount Defiance; 122, Mount Etna; 5, Newark Bay; 61, New Baltimore; 46, New Hamburg and Wappinger Creek; 63, New Scotland; 65, Newtonville; 37, New Windsor; 114 North Branch of Bouquet River and Tower's Forge; 62, Oniskethau, Spraytkill, and South Bethlehem; 20, Ossining (Sing Sing); 6, Passaic River; 2, Perth Amboy and Arthur Kill; 121, Peru; 117, Port Douglas; 88, Queensbury, Round Pond, and Jenkins Mills; 1, Raritan River and Bay; 115, Reber; 54, Rondout; 39, Roseton; 79, Round Lake; 88, Round Pond, Queensbury, and Jenkins Mills; 104, Rutland-Addison County Line; 123, Salmon River and Schuyler's Falls; 81, Saratoga Lake; 68, Schoharie Creek; 123, Schuyler's Falls and Salmon River; 20, Sing Sing (Ossining); 132, Snake Mountain; 101, South Bay; 62, South Bethlehem, Spraytkill and Oniskethau; 124, South Plattsburg; 14, Sparkill Valley; 62, Spraytkill, South Bethlehem, and Oniskethau; 28, State Camp; 71, St. Johnsville; 18, Stony Point; 75, Teller Hill; 106, Ticonderoga; 114, Tower's Forge and North Branch of Bouquet River; 128, Treadwell Bay; 52, Ulster Park; 25, Verplanck's Point; 64, Voorheesville; 111, Wadham's Mills and Bouquet River; 46, Wappinger Creek; 47, Wappinger Falls; 130, West Beekmantown; 50, West Park; 112, Whallonsburg; 116, Willsboro; 130, Winooski River; 3, Woodbridge Creek; 96, Wood Creek; 141, West Milton and La Moille River.

and for the report on the *Glacial Geology of New Jersey*,[1] under Professor Salisbury's guidance, work bearing on the problems here involved was carried out in 1897 and 1901. The main results here presented were in hand before the latter date, and the advance since then has been mainly in determining the crustal movement and in the analysis of facts bearing on the origin of the Hudson water body. To Professor Salisbury the writer is under obligation for the opportunity of detailed study of the Pleistocene formations of New Jersey and adjacent portions of New York, for early training in methods of investigation and mapping of those formations, and for suggestions in the original plans for the work, the results of which are here presented. To Professor Chamberlin the writer is under obligation for assistance with difficulties encountered in this investigation, and for continued inspiration to perseverance in searching out the truth. Neither Professor Chamberlin nor Professor Salisbury is responsible for opinions here expressed or for any failure to arrive at the truth.

GENERAL STATEMENT OF TOPOGRAPHY OF EASTERN NEW YORK AND SOUTHERN NEW ENGLAND.

Southern New England has been described as an upland rising gradually inland from the sea and reaching elevations of 1,500 to 2,000 feet in southern New Hamsphire and Vermont.[2] Above this upland there rise higher elevations such as Mt. Monadnock, and groups of elevations such as the Green Mountains and the White Mountains. Below the upland, valleys have been sunk, a small amount near the sea, but deeper farther inland. These valleys are broad on the soft rocks and narrow on the harder rocks.

Without assuming an identical history, this picture may be transferred to eastern New York, where, as a first approximation to the truth, the country may be pictured as a rolling surface rising inland from the narrows at Long Island and Staten Island. Above this surface there are elevations, such as the Adirondacks and the Green Mountains. Below it there are depressions, such as the Hudson and Champlain Valleys.

[1] See *Glacial Geology of New Jersey*, by ROLLIN D. SALISBURY, assisted by HENRY B. KUMMEL, CHARLES E. PEET, AND GEORGE N. KNAPP (Vol. V of the Final Report of the State Geologist, 1902).

[2] DAVIS, *Physical Geography of Southern New England*.

The Hudson Valley has three natural divisions: (1) the part south of the Highlands from Peekskill to the narrows at Brooklyn; (2) the Highlands from Peekskill north to near Fishkill; and (3) the broader Hudson Valley from near Fishkill to north of Glens Falls.

North of the Hudson Valley is the Champlain Valley, to which two passages lead, one by way of Lake George and the other east of the Lake George pass by way of southern Lake Champlain. The broader Hudson Valley and the Champlain Valley have been considered the northeastward continuation of the Greater Appalachian Valley.

SUB-LACUSTRINE OR SUB-MARINE GLACIAL DEPOSITS IN THE HUDSON AND CHAMPLAIN VALLEYS.

In the bottom of the Hudson and Champlain Valleys there has been built in recent geological times a plain mainly of clay, with margins frequently of gravel and sand.[1] This plain has the form of an old lake-floor or old sea-floor. The clay plain is best seen in the northern part of the Hudson from Catskill north. In the southern part of the valley—from Poughkeepsie south—it is either absent entirely, or is to be seen only in limited areas, and generally covered with gravel and sand. The clay in both the Hudson and Champlain Valleys is laminated, with alternate "fatty" and sandy laminæ having a thickness of one-fifteenth of an inch or more. (See Fig. 2.) The laminæ are sometimes grouped into beds a few inches in thickness, separated by rather prominent lines of parting. In one place ripple marks were seen. (See Fig. 3.) The clay often shows faulting and frequently shows joint structure conspicuously. (See Fig. 2.) It is sometimes contorted. The upper part of the clay is generally yellow in the Hudson Valley and brownish-red in the Champlain Valley. The

[1] The clays and gravels and sands of the Hudson Valley have been described in considerable detail by F. J. H. MERRILL AND HEINRICH RIES in the *Tenth Annual Report of the New York State Geologist*, and by MR. RIES in the *Bulletin of the New York State Museum*, Vol. III, No. 12. The former report was in hand in the field, and while the interpretation placed on these deposits is quite different, the writer wishes here to make general acknowledgment of its aid in his studies. Specific acknowledgment is made in the proper place where this report has been drawn upon for facts beyond the writer's personal observation. The writer also had the aid in the field of the article by S. PRENTISS BALDWIN on "The Pleistocene History of the Champlain Valley," *American Geologist*, Vol. XIII (1894), pp. 170–184.

lower part is blue. Bands and blotches of yellow often occur in the midst of the blue layers in the Hudson Valley. The clay often contains concretions. In thickness the clay varies from a small amount

FIG. 2.—Showing joint structure in the laminated clay of the Hudson Valley.

to 215 feet in the valley of the Hackensack and zero to 243 feet[1] in the Hudson Valley, where it is commonly 80 to 100 feet or more thick. In the Champlain Valley it is known to have a thickness as great as 60 to 75 feet, but is generally thinner than in the Hudson Valley.

[1] H. RIES, *Bulletin N. Y. State Museum*, Vol. III, No. 12, p. 184.

The clay overlies till (Fig. 4), gravel and sand, or rock surfaces, which are frequently striated. It fits into the irregularities of the till, or the stratified gravel and sand which sometimes appears to have the form of kames. In the upper Hudson the underlying stratified sand and gravel often has a high angle of dip, generally southward, but sometimes in other directions. These layers are interpreted as representing deposits made by the ice waters in the standing body of water as the ice was retreating. This structure can frequently be seen from the car windows of the New York Central Railroad. The marginal

FIG. 3.—Ripple marks in the clay at New Windsor.

deposits of gravel and sand have the form of plateaus of two distinct classes:

Class 1.—Gravel terraces and plateaus with undulatory topography on the edge toward the Hudson, which sometimes assumes a more or less kame-like or morainic form, or with the edge next to the Hudson higher than the edge next to the valley wall, and with the dip of the layers of gravel and sand toward the valley wall and downstream. This phase of the drift is the characteristic phase in the Highlands, and is not accompanied by a clay plain.

Class 2.—The second phase of the stratified drift consists of gravel plateaus and terraces with the undulatory edge toward the

valley wall, and the smoother and lower edge toward the Hudson.[1] The inner and higher edge is sometimes marked by distinct kames or by moraine. The structure is delta-like. The layers usually dip at high angles toward the Hudson, and the coarse gravels and sands grade rapidly down the dip of the layers into fine laminated clay. (See Fig. 5, *A* and *B*, and Fig. 6.) In the clay and over the clay there are sometimes masses of till. (Fig. 4.) In the till there are sometimes masses of clay. Over the clay there often is coarse gravel with a subdued undulatory topography, and the contact of the

FIG. 4.—Showing till both above and below the clay at Haverstraw.

gravel and clay is of such a nature as to indicate that the gravel has been forcibly pressed against the clay surface. This phase of the gravel plateaus is the characteristic phase of the Appalachian Valley division of the Hudson Valley, and is usually associated with a wide clay plain. These two classes may be referred to as high-level terraces. On the whole, they increase in altitude from south to north, but not at a uniform rate or continuously. They indicate a water

[1] Some of the smoother plateaus may properly be called subaqueous overwash plains. See R. D. SALISBURY AND HENRY B. KÜMMEL, *Annual Report of State Geologist of New Jersey*, 1893, pp. 266–68; and R. D. SALISBURY, *Glacial Geology of New Jersey*, pp. 130–33.

body in the Hudson and Champlain Valleys as the ice was retreating after making the Brooklyn-Perth Amboy moraine.

Below the level of the high-level gravel plateaus there are two classes of deposits: (1) secondary deltas; (2) river terraces. The former have been recognized with certainty only in the northern Hudson. The latter occur in the northern Hudson Valley and in tributary valleys both in the northern and southern parts of the Hudson. In these lower terraces pebbles of clay occur rarely, evidently derived from the erosion of the higher clay deposits.

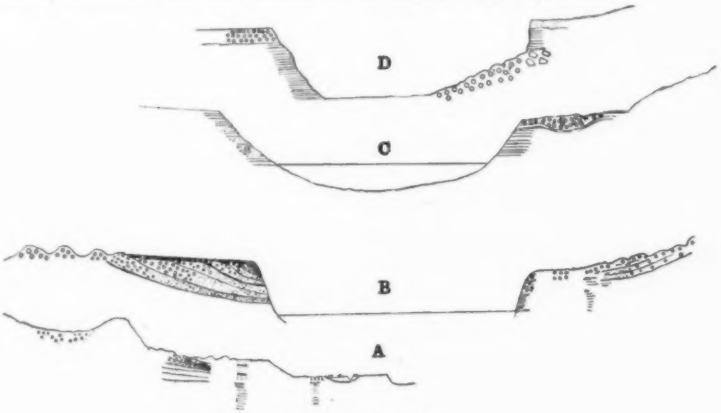

FIG. 5.—Diagrammatic sections:

[*A*, of Haverstraw gravel plateau from west to east; *B*, of Newburg delta and moraine at the left and Dutchess Junction gravel plateau with morainic east edge on the right; *C*, a section similar to and about one mile south of *D*; *D*, Roseton on the left and the northern part of the Low Point deposits on the right. Parallel horizontal lines represent clay.

In the Hudson Valley this old sea- or lake-floor plain is naturally divided into three portions roughly corresponding with (1) the portion south of the Highlands, (2) the Highlands, and (3) the Hudson Valley north of the Highlands. Deposits in a lowland west of the Palisade Ridge will be described in connection with Division 1.

HUDSON VALLEY SOUTH OF THE HIGHLANDS AND LOWLAND WEST OF PALISADE RIDGE.

From the narrows at Brooklyn northward to the Highlands the land rises gradually, as a slightly rolling upland, best represented by the even crest of the northern part of the Palisade Ridge, and by the

level to which the hilltops reach east of the Hudson.[1] Below the level of this upland to the west of the Palisade Ridge there is a lowland. Below the surface of this lowland 100–150 feet there are

FIG. 6.—Photograph showing gradation of gravel and sand down the dip of the layers into clay, in the part of the Newburg delta north of the Quassaic. The workman's shovel marks the point where one of the layers of gravel and sand at the left changes into clay.

valleys[2] in which there are deposits of gravel, sand, and clay, presently to be described. In the valleys in the southern part of this

[1] *New York City Folio*, U. S. Geological Survey; *Geography* by R. E. DODGE AND BAILEY WILLIS, p. 1.

[2] *Physical Geography of New Jersey*, R. D. SALISBURY, p. 141.

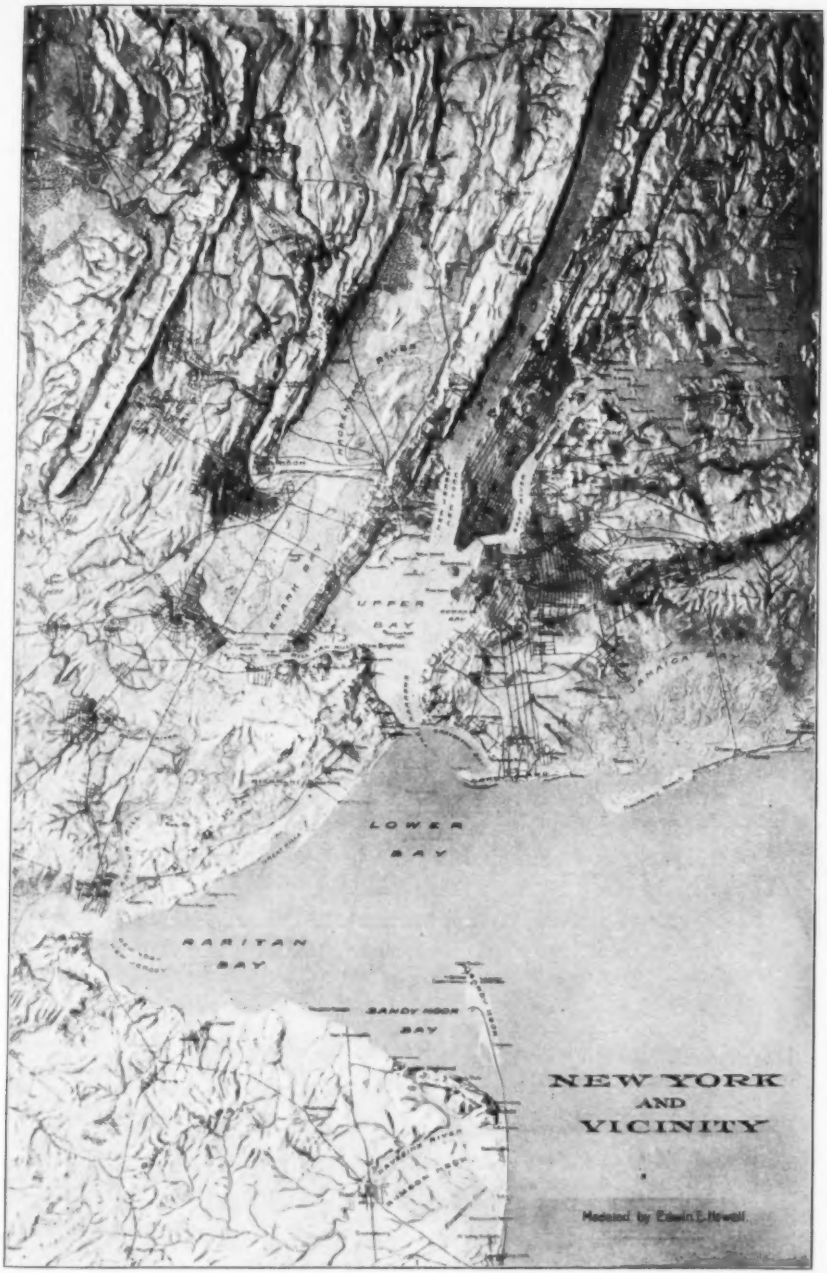

Fig. 7.—Model of New York City and vicinity.
[Copyright by Edwin E. Howell; printed by permission.]

lowland there are salt waters, which in their widest expanse constitute Newark Bay. (See Fig. 1, No. 5, and Fig. 7.)

The upland surface represented by the even crest of the Palisade Ridge is a remnant of the Cretaceous peneplain. The lowland surface represents a later peneplain developed on the softer rocks of the Triassic area.[1] The valleys in this lowland represent erosion in pre-last glacial and post-Pensauken time. The stratified drift in these valleys was deposited largely by ice waters on the retreat of the ice from the Brooklyn-Perth Amboy moraine.

Below the upland surface and at the east base of the Palisade Ridge is the Hudson Valley, now occupied by the waters of the Hudson estuary. Along the sides of the valley and below the waters of the Hudson estuary there are deposits of stratified gravels, sands, and clays similar in origin to those in the lowland west of the Palisade Ridge.

Below the waters of the Hudson estuary and of Newark Bay there are certain submerged channels which are shown in Fig. 8 and will be referred to later.

BROOKLYN-PERTH AMBOY MORAINE.

Across the southern end of both the Hudson Valley and the lowland west of the Palisade Ridge there is the massive and complex ridge which forms the Brooklyn-Perth Amboy terminal moraine.[2] It is popularly referred to as the backbone of Long Island, and it also makes the more conspicuous elevations of the southwestern part of Staten Island. Through this moraine there are two gaps—one at the south of the Hudson and the east end of Staten Island called the Narrows, and the other at the west end of Staten Island occupied by Arthur Kill. (See Fig. 8.)

[1] This is called the Somerville peneplain by Professor W. M. Davis, and the pre-Pensauken peneplain by Professor R. D. Salisbury (*loc. cit.*, pp. 114–15).

[2] See R. D. SALISBURY, *Glacial Geology of New Jersey*, Chap. 9, and *New York City Folio*, U. S. Geological Survey. T. C. CHAMBERLIN, *Third Annual Report*, U. S. Geological Survey, 1881–82, pp. 377–79; WARREN UPHAM, *American Journal of Science*, 1879, pp. 81–92 and 179–209; G. H. COOK AND J. C. SMOCK, Geological Survey of New Jersey, *Annual Reports* for 1877, 1878, and 1880.

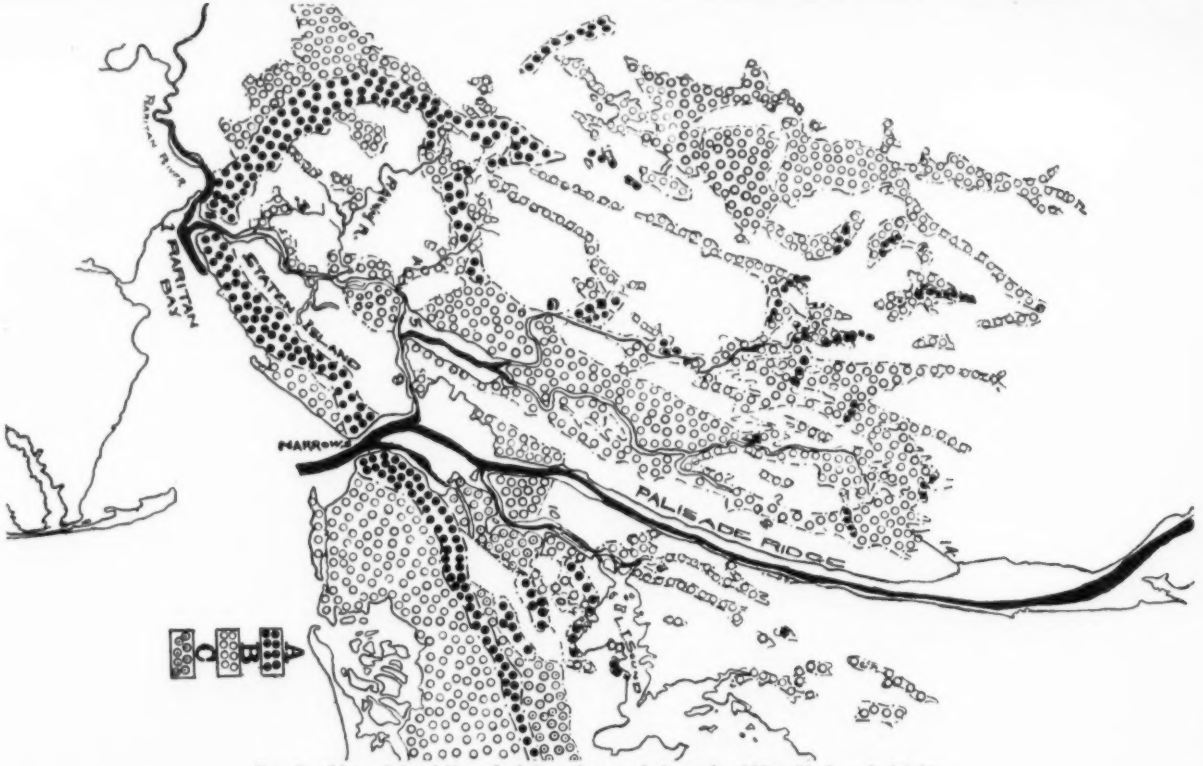

FIG. 8.—Map of the drift and of the submerged channels of New York and vicinity.

[Taken from Plate 28 of R. D. Salisbury's *Glacial Geology of New Jersey* and from the *New York City Folio* of the U. S. Geological Survey. Some belts of thicker drift including kame belts and morainic areas are shown which were mentioned in the text of the former, but not included in Plate 28. On Long Island some belts are marked which were mapped partly as kames and partly as till areas. The submerged channels were traced from data obtained from the *U. S. Coast Survey Charts*.]

LEGEND: *A*, belts of thicker drift including kame belts and morainic areas which are believed to mark halting places of the ice. *B*, areas of stratified drift with kames not included in *A*, and including some small areas of dune sand. *C*, mixed till and stratified drift. Till areas are shown in white, submarine channels in black.

I, Raritan Bay; 2, Perth Amboy and Arthur Kill; 3, Woodbridge Creek; 4, Elizabeth River; 5, Newark Bay; 6, Passaic River; 7, Hackensack—city and river; 8, Englewood; 9, Kill van Kull; 10, East River; 14, Sparkill Valley.

DRIFT OF LONG ISLAND AND STATEN ISLAND INSIDE THE BROOKLYN-PERTH AMBOY MORAINE.

Inside or north of the Brooklyn-Perth Amboy moraine a number of positions taken by the ice on its retreat are marked by moraines or kame belts, or other similar phenomena. Near the west end of Long Island at least two, and probably three, such belts are represented more or less discontinuously. (See Fig. 8.) Possibly one such position is represented on Staten Island.

DRIFT OF THE LOWLAND WEST OF THE PALISADE RIDGE AND NORTH OF THE BROOKLYN-PERTH AMBOY MORAINE.

On the higher part of the lowland west of the Palisade Ridge and inside the Brooklyn-Perth Amboy moraine, there is an extensive series of belts of thicker drift, with more or less distinct morainic topography, or elongate belts of kames with the aspect of moraines, which are frequently bordered by plains of gravel and sand with the form of overwash or outwash plains. In some places such aggradation plains have no definite kame or morainic areas at their source. On the lower part of the lowlands there is a complex series of gravel and sand plains or plateaus, some of which head in kames, but others have ice-molded, but kameless, sources.

Some of the plains have delta-like forms and delta-like structures. The elevations of these plains at the south are 20–40 feet, while farther north plains whose structure is unknown have elevations of 80–100 feet.[1] These deposits are found north from the latitude of Hackensack and Englewood well toward the northern border of the state. Underneath the gravel and sand of these plains, or spread out to the southward with little overlying sand or gravel, there is laminated clay which frequently has a thickness of 100 feet and sometimes as great as 215 feet. This clay extends south of the latitude of Hackensack and Englewood, and is also found to the north.[2]

[1] See R. D. SALISBURY AND C. E. PEET, "Drift Phenomena of the Palisade Ridge," *Annual Report of State Geologist of New Jersey*, 1893, pp. 105–210; and *idem*, "Drift of the Triassic Plain of New Jersey," *Glacial Geology of New Jersey* (Final Report of State Geologist, Vol. V), Chap. 12, and especially pp. 506–13, 595–628, 632–42.

[2] The areal distribution of a large part of these deposits is shown in the maps of the *New York City Folio*, U. S. Geological Survey. See also Fig. 8 of this article.

FIG. 9.—Map showing some of the areas of stratified drift along the Hudson from north of Sing Sing to north of Camelot.

LEGEND: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-moulded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. *F*, clay chiefly, but other forms of stratified drift are included; knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H*, boundary lines showing approximate limits of the features inclosed. The white space next to the streams marks swamps, flood-plains, and low-level terraces.

14, Sparkill Valley; 15, Haverstraw and Minisceongo Creek; 17, North Haverstraw and Cedar Pond Brook; 18, Stony Point; 19, Jones' Point; 20, Sing Sing (Ossining); 21, Croton Point and Croton River; 22, Croton Landing; 23, Oscawanna; 24, Crugers; 25, Verplanck's Point; 26, Peekskill—village and creek; 27, Annsville; 28, State Camp; 29, Roye Hook; 30, Highland Falls; 31, West Point; 32, Indian Brook; 33, Cold Spring and Foundry Brook; 35, Breakneck Mountain; 36, Cornwall; 37, New Windsor; 38, Newburg and Quassaic Creek; 39, Rosetoa; 40, Marlboro; 41, Dutchess Junction; 42, Fishkill and Fish Kill; 43, Walcotville; 44, Carthage Landing and Low Point; 46, New Hamburg and Wappinger Creek; 47, Wappinger Falls; 48, Camelot; 49, Poughkeepsie.

DRIFT IN THE HUDSON VALLEY SOUTH OF THE HIGHLANDS AND NORTH OF LONG ISLAND AND STATEN ISLAND.

The deposits of drift of special significance in this area occur north of Ossining (Sing Sing), where the valley begins to broaden out into Haverstraw Bay. Most of the deposits south of here are covered by the "Surficial Geological Maps" of the *New York City Folio*, and are mentioned in its text. The deposits of drift of special significance in this part of the valley belong to the two classes of high-level terraces mentioned above (p. 228). The features of Class 1, similar to those found in the Highlands, are found (1) in a terrace at 120–100 feet A. T. from north of Sing Sing to south of Croton River mouth; (2) at Jones Point; and (3) features of similar import occur at Roye Hook near State Camp, Peekskill. These features are shown in Fig. 9, the first between Nos. 20 and 21, the second at No. 19, and the third at No. 29. To which class some of the features of a high-level terrace from Peekskill toward Oscawanna belong is a question. (See Fig. 9, Nos. 23, 24, 25). The features of Class 2, similar to those prevailing in the Appalachian Valley part of the Hudson, occur at Croton Point and Croton Landing on the east side of the river, and from Haverstraw to north Haverstraw on the west side. (Fig. 9, Nos. 21, 22, and 15 and 17.)

Haverstraw.—The deposits at Haverstraw of interest in connection with this paper are of four types: (1) the narrow moraine at the foot of the Palisade Ridge; (2) a gravel plateau with undulatory topography and delta-like structure at an elevation of less than 120 feet A. T., which is underlain by laminated brick clays, yellow in color above, and blue below; (3) low-level gravel and clay.

1. The moraine: The position of the ice-edge as it rested near the northern base of the Trap Ridge, which farther south makes the Palisades of the Hudson, is marked in the southern part of Haverstraw by a narrow moraine with a west-by-north and east-by-south trend, parallel approximately to the trend of the Trap Ridge. Where well-defined this moraine has a width of one-fourth to one-half of a mile. It has been traced for a distance of about two miles, from a point about one mile southeast of Thiell's Station to within something less than three-fourths of a mile northwest of Short Clove. It extends farther east in the form of a ridge, but with less definition

as Short Clove is approached. At its best the moraine shows a relief between hillocks and hollows of between 20 and 30 feet. (See Fig. 9, No. 15). Some of the hillocks are composed largely of stratified drift, but, so far as exposures show, a considerable part of the moraine is made up of till which is prevailingly of gneissic materials. There are places, however, where it shows a conspicuous red color from the abundance of Triassic constituents.

2. The Haverstraw gravel plateau has been sometimes called the Haverstraw delta. It extends from about the lower edge of the moraine above mentioned northward to Cedar Pond Brook, and descends from an elevation of a little less than 120 feet on the west to 40–60 feet on the east, where it falls off abruptly to a lower plain bordering the Minisceongo and Cedar Pond Brooks.

Fig. 10.—Cross-section of the Appalachian Valley (after Davis).

AB, uplands; *CD*, general valley lowland. Horizontal lining shows clay.

The topography of the plateau for the most part appears at first sight to be quite plain, with a general slope eastward and southeastward. In the northern part, however, it becomes quite undulatory, and there are some depressions as great as 20 feet in depth, one of which is situated in a long conspicuous ridge extending north and south parallel to the road west of it, leading from West Haverstraw to North Haverstraw. This ridge is separated from the higher land to the west by a considerable trough-like hollow. On closer examination much of the surface, which at first sight appeared to be quite plain, is found to be affected by ridge-like undulations and hollows with a relief of 6, 8, and 10 feet These undulations extend eastward nearly to the abrupt east front. (See Fig. 5, *A*.)

Structure and materials: Exposures are abundant in this plateau. In the higher western portion numerous gravel and sand pits show stratified sands and gravels more or less horizontal in the upper few feet, and dipping at high angles below in an easterly and southerly direction. A little eastward these stratified gravels are said to overlie clay, and still farther eastward exposures are of such a nature that it is quite certain that the gravels and sands grade into finer materials, and into clay with alternate layers of fine sand, and finally into the laminated brick clays.

While stratified materials appear to prevail in the capping of the clay, a number of places are to be found where the material is not stratified, and where it has the character of a compact till showing indications, at the contact with the clay, of having been subjected to a pressure which forced the clay and the till together. The contact surface is irregular. (Fig. 4.) The clay surface rises and falls as much as 2 feet in a distance of 10 feet, while the layers of clay show contortion in the upper part. In earlier observations compact lumps of clay were noted in till-like material. Before it was firmly established that till overlies the clay, the writer did not feel sure that in the extraction of the clay for brick-making the lumps of clay had not become artificially mixed with till. It seems reasonably certain now, however, that the observed clay lumps in the till were not introduced artificially. Underlying the clay stratified gravel and sand was observed in some places with a topography which suggested buried kames. In other places till was observed with some constituents that are not present in the overlying till. Flowing springs and flowing wells arising from this underlying gravel and sand indicate that the water has access to these porous layers at higher levels.

North Haverstraw.—The gravel plateau at North Haverstraw very likely was once continuous with that described south of Cedar Pond Brook. It has a general elevation of something less than 120 feet A. T. on its west side, and a large part of its total area is 100 feet A. T. It descends abruptly 100 feet to the meadow along Cedar Pond Brook on the south, and on the northwest it descends abruptly to a plain at about 20 feet A. T. On the northeast the descent is to a kame-like gravel knoll at about 50 feet A. T. On the east there is a similar knoll. Each of these knolls is indicated by a black circle at No. 17 in Fig. 9. On the southeast the descent is to a terrace-like form at 40 feet, and farther south to a ridge of gravel of uncertain origin at 60 feet A. T.

The west and northwest sides of the plateau have a gently undulatory topography, and the surface of the plateau farther east has some ridge-like irregularities that suggest the presence of the ice during its deposition.

Materials and structure: There are no good exposures in this conspicuous plateau, although exposures occur in the lower gravel

forms to which the steep edges of the plateau descend. The indications from the surface and from well data are that it is composed of gravel and sand. A well on the top of the plateau near the west side at the house of Mr. Neely is reported to have penetrated 120 feet of gravel and sand from an elevation of 100 feet A. T. without reaching rock.

The kame-like gravel knoll at the northeast edge of the plateau is situated south of the North Haverstraw Station of the West Shore Railroad. An exposure shows about 20 feet of coarse gravel. Farther south, east of the railroad, where the gravel likewise has a kame-like form, the layers dip north and south and east. North of these kames toward Stony Point clay occurs up to 40–60 feet, and has a form which may be due to erosion.

Low-level gravel, and clay. What appear to be low-level terraces derived from the erosion of the higher gravels have been observed in the form of discontinuous shoulders on the north side of the Haverstraw gravel plateau on the slope to Cedar Pond Brook at elevations of 60 and 40 feet. A 40-foot level on the southeast side of the North Haverstraw plateau, and also a 60-foot level southwest from the 40-foot level, may represent a product later in origin than the plateau itself. It may be said, however, that where the level of stratified drift varies so greatly as it does in this region it is not easy to determine positively that the shoulders of limited area and uncertain relations are of later origin than the higher gravels, and do not represent remnants of undulations descending to the lower levels made while the ice was present. A wide plain extending along the water front from near Short Clove to Grassy Point, with an elevation by the topographic map of less than 20 feet A. T., has been so worked over in the making of bricks that it is difficult to say what was its original height and extent. Some exposures have been observed in it in which the materials included rounded pebbles of clay, evidently derived from the erosion of the higher level clays. In exposures near at hand and at about the same level the layers have a southerly dip at a high angle, thus suggesting lower-level delta deposits made from the erosion of the higher gravels and clay. At Grassy Point (south of No. 17, Fig. 9) there are deposits in this lowland which were made in the presence of the ice.

No exposures which reveal the structure occur in the 60-foot and

40-foot levels south of Cedar Pond Brook. The 40-foot level at North Haverstraw is well exposed. In no part of the exposure was the delta structure seen which is so common in the high-level gravels,

FIG. 11.—The Catskills and the lowland in the Appalachian part of the Hudson Valley.

[From A. P. Brigham, *Geographic Influences on American History;* courtesy of Ginn & Co.]

and there is said to be no clay underlying the stratified gravel here for a considerable depth at least.

Interpretation: (1) Ice present with its edge resting on the moraine at the foot of the Trap Ridge and with a general west-by-north and east-by-south direction on the west side of the Hudson.

(2) The ice retreated so that, either at one time or at successive positions, its edge occupied the Haverstraw and North Haverstraw gravel plateaus.

(3) The ice waters discharged into a standing body of water and built up the deposits of gravel and sand, with the steep dipping layers of gravel rapidly grading into sand and then into clay. The clay was deposited on the irregular surface of the drift previously deposited.

FIG. 12.—Part of the Newburg delta, on the south side of the Quassaic. Looking west.

(4) The ice, either by re-advances, or because of more favorable conditions in some places than in others while continually present, worked over the clays, producing some of the contortions observed, and involving masses of clay in the till which it deposited over the clay in favorable places. The water-worn gravel was in places brought under pressure, and the contact of the clay with the gravel was thereby made more intimate.

(5) On the retreat of the ice and the fall of the water-level the higher-level gravels were eroded by the Minisceongo and Cedar Pond Brook, thus producing deposits at lower levels. Whether there are remnants of lower-level deltas cannot be confidently stated. They would naturally be expected.

(6) After deeper erosion by the streams than the present Hudson level, submergence took place, thus drowning the mouths of the tributary streams.

Croton.—On the east side of the river at Croton Point, and Croton Landing, deposits of similar import occur, but not identical in detail, with those on the west side of the river. Lack of space forbids detailed description.

Oscawanna—Crugers—Peekskill.—Clays and gravels: The clays and gravels in the city of Peekskill and south to Oscawanna show phenomena which in some features are similar to, and in other features are unlike, those at Haverstraw and Croton. They are evidently deposits made later than the last-mentioned deposits. Their relations, however, to any marked and definite position of the ice-edge are not so well shown. The approximate area of these deposits is shown in Fig. 9 between Nos. 23 and 25.

The deposits in this region are notable for their irregularity in level. The clay surface varies from an elevation approaching 100 feet A. T. to tide-level. It is in most cases covered with sand, or gravel, and in a broad statement it may be said that the finer materials predominate at the south, while at the north the materials overlying the clay include both fine materials and coarse gravels with bowlders up to five feet in diameter. In one or two instances till has been found overlying the clay in this region.

The structure of the stratified materials overlying the clay even at high levels does not generally show the high angle of dip so common in the high-level gravels at Haverstraw and Croton.

The high-level terrace has an elevation of 100–120 feet A. T. Parts of it, however, reach lower levels—60–80 feet A. T., and perhaps less. It is somewhat difficult to discriminate between what may properly be called high-level terrace and what may properly be called low-level terrace. Terraces at low levels exist at 60, 40, 30, and 10–20 feet A. T. In general, these terraces are covered by gravel and sand. The gravel is sometimes very coarse, containing bowlders as large as five feet in diameter. The relations to the clay are not always distinguishable. It is not an uncommon relation, however, to find these low-level gravels much lower in level than clay in the immediate vicinity. It is questionable, however, if in all cases this relation has been brought about by the erosion of the higher-level deposits. It is conceivable that some of the low-level deposits are original deposits by the ice water, which simply failed to build up at

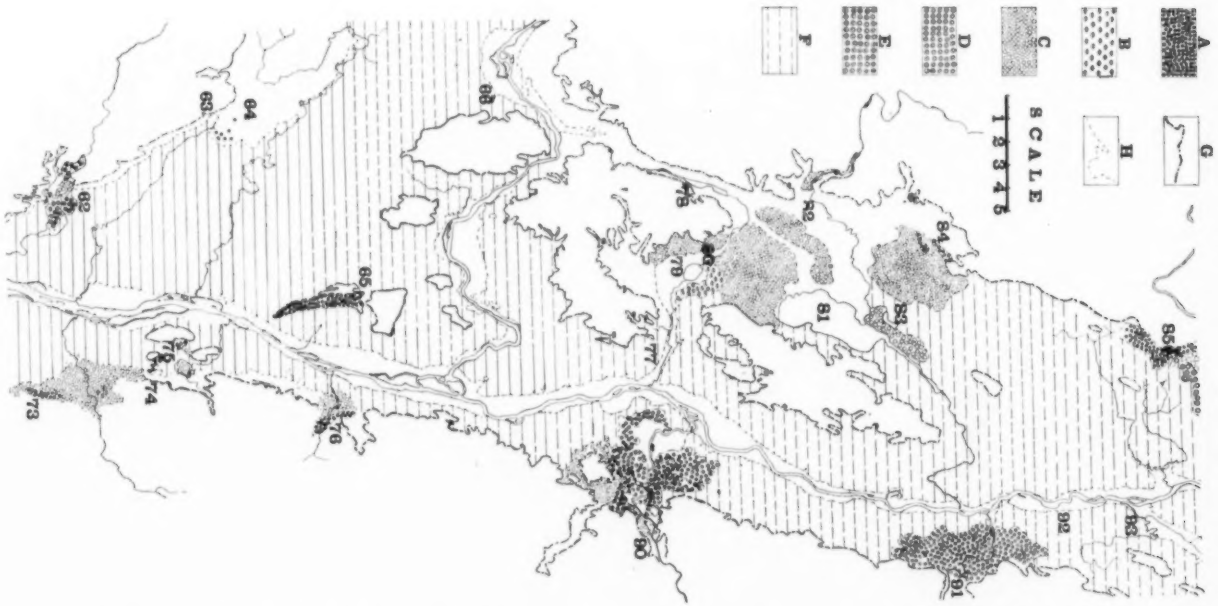

FIG. 13.—Showing principal areas of stratified drift along the Hudson from latitude of South Schodack to north of Saratoga Springs.

LEGEND: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-molded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. On the Batten Kill some of the ice-water deposits may be included in the areas covered by this device. *F*, clay chiefly but other forms of stratified drift are included. Knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H* boundary lines showing approximate limits of the inclosed features. The white space next to the streams marks swamps, flood-plains, and low-level terraces.

62, South Bethlehem, Sprayt Kill and Oniskethau Creek; 63, New Scotland; 64, Voorheesville; 65, Newtonville; 66, Schenectady; 73, South Schodack; 74, East Greenbush; 75, Teller Hill; 76, Troy; 77 Mechanicsville; 78, Ballston Lake; 79, Round Lake; 80, Maltaville; 81, Saratoga Lake; 82, Ballston Spa; 83, Lonely Lake; 84, Saratoga Springs; 85, Moreau Pond; 90, Hoosic River; 91, Batten Kill; 92 Fort, Miller; 93, Moses Kill.

these particular places to the level reached in adjacent places. It may be said that this relation is more clearly shown by phenomena seen elsewhere. The facts in this locality are sufficiently doubtful, at any rate, to justify caution in asserting the erosion origin of the irregularities in the clay. However, there are some facts which seem to indicate a considerable amount of erosion of the clay in this region and subsequent deposition of gravel in the clay channels.

Jones Point and State Camp near Peekskill.—At Jones Point a narrow terrace less than a mile in length occurs on the right side of the Hudson. It is made up mainly of stratified gravel and sand and a little clay, and formerly contained more clay.[1] The terrace has an elevation at its north end of about 100 feet A. T., and at its south end of about 60–80 feet, and at present, in places at any rate, is higher toward the Hudson than toward the valley wall. See Fig. 9, No. 19.

At State Camp (28) near the mouth of the Peeks Kill there is a gravel plateau with an elevation of 100 feet A. T. whose flat top is used by the New York state militia as a camping and parade ground. This plateau continues up the valley of Sprout Brook with some breaks, to a point about one mile northeast of Annsville (27), where it has an elevation of 140–160 feet A. T. It was not studied beyond this point. It also extends northward up the valley of the small tributary north of State Camp and southeast of Wallace Pond. Its greater development occurs, however, at State Camp on the right bank of Peeks Kill. A small remnant occurs farther upstream on the left bank. While the plain surface as a whole rises upstream, the northern portion of it at State Camp slopes eastward—a fact of some significance perhaps in determining the history of the plateau.

The exposures in this plateau show gravel overlying clay. The clay reaches higher above sea-level near the extremity of the plateau than farther upstream, thus indicating a gradation of coarse materials from upstream into the fine clay. Low-level terraces occur farther downstream on both right and left sides of the stream at 30–40 feet A. T.

Roye Hook.—West of the plateau near the State Camp Station of the New York Central Railway there is an isolated hill of small dimensions, reaching an elevation of 100 feet A. T. This is called

[1] See H. RIES, *Tenth Annual Report State Geologist of New York*, p. 114.

Roye Hook (29, Fig. 9). At its base, both on the north and on the south, there are low-level terraces at about 30 feet. In the Roye Hook hill a large gravel and sand pit shows about 10 feet of fine sand and gravel overlying 5 feet of silt, both sand and silt being horizontally stratified, or nearly so. But under the silt there is about 85 feet of coarse gravel and sand, with layers dipping at a high angle eastward and southeastward. The gravel and sand in this lower portion of the exposure were not observed to grade into clay, as they were observed to do at Croton, and as they apparently do at Haverstraw. The phenomena at Jones Point and Roye Hook are more nearly allied to deposits which occur in the Highlands than they are to those that occur in the broader part of the valley to the south. These characteristics are discussed in the description of the Highlands phenomena.

THE HIGHLANDS OF THE HUDSON.

As indicated above in the description of the general features of the Hudson, south of Newburg and Fishkill the Hudson leaves the Appalachian district and crosses through the plateau to the south in that part of its course designated the Highlands of the Hudson. The features of the rock valley here differ radically from those at the north, and in place of a broad dissected lowland between distant uplands, like that in the Appalachian Valley, or of the broad amphitheater between distant uplands like that at the north edge of the Palisade Ridge at Haverstraw, we have the upland descending abruptly from elevations of 1,100 and 1,400 feet to the waters of the estuary, which is here generally from four-fifths to seven-tenths miles wide, and reaches a maximum width of one and three-fifths miles.

In this narrow valley the gravel plateaus are present, but if there is a clay plain, it is covered by the waters of the estuary, or is represented by a few limited remnants only.

The gravel plateaus in the Highlands of the Hudson have characteristics which are typical of Class 1 above described, and indicate the presence of the ice in the valley while these deposits were accumulating. There are situations however, where streams of water came from the ice outside of the immediate Hudson River valley and deposited their loads on slopes toward the center of the valley. Such

phenomena occur where streams head northward from their debouchure, and are represented, it is believed, by a part of the State Camp deposits on the southern edge of the Highlands. The gravel plateaus of the Highlands that were examined are (1) at West Point and south toward Highland Falls (30); (2) at Cold Spring (33) and south toward Garrison. The stratified drift at Roye Hook near State Camp, perhaps part of the State Camp plateau where the surface slopes east-

FIG. 14.—Looking across the clay plain of the upper Hudson.
[Photograph by W. S. McGee.]

ward, and the Jones Point plateau, on the southern edge of the Highlands have characteristics similar to those in the Highlands and indicate a similar disposition of the ice in respect to the valley when they were building.

North of West Point in the Highlands there is little left of any former valley filling, if the valley ever was filled. One or two miles south of Storm King, on the right bank of the Hudson, a remnant of clay in a terrace form was observed at an elevation estimated at 60 feet, and nearer Storm King another remnant was observed. On the left bank there are several remnants of clay or gravel, the most conspicuous of

which is a terrace of coarse gravel on the south side of Breakneck Mountain (35, Fig. 9) with an estimated elevation of 80 feet.

The weight of evidence in this part of the Hudson indicates that the ice protruded as a tongue down the valley, and that it was influential in shaping the edge of the plateaus toward the Hudson. An alternative hypothesis is that the ice retired in a northeasterly direc-

FIG. 15.—Looking eastward from the bluffs north of Albany across the trench of the Hudson, cut into the clay plain.

tion; that the plateaus on the west side of the valley were made first and had their east edge shaped by the ice-front; and that later those on the east side of the valley were constructed and had their east edge shaped by the ice. This alternative hypothesis, however, does not explain the eastward-dipping layers of the plateaus on the east side of the valley, nor does it explain the apparent lower elevation of some parts of the terraces on the east side next to the valley wall. It would explain successive undulations from lower levels near the Hudson to higher levels away from the Hudson, such as are found at Cold Spring (33, Fig. 9).

HUDSON VALLEY NORTH OF THE HIGHLANDS.

The valley north of the Highlands has been considered the northeastward continuation of the Greater Appalachian Valley. It lies between the upland surface on the east, which in New England is called the New England Plateau, and on the west it is limited by the Alleghany Front which is the steep slope from the Alleghany Plateau to the Greater Appalachian Valley, and of which the dissected edge is called the Catskill Mountains. Below the level of these eastern and western plateau surfaces there is a broad lowland. Below the level of this lowland surface there are deep valleys. In the bottom of these valleys there are the deposits of stratified drift which have the form of an old lake- or sea-floor. Below this old lake- or old sea-floor there are valleys and other depressions. In the bottom of the Hudson Valley is the Hudson estuary, and beneath its waters is the submerged Hudson channel described below. In this region and farther to the southwest, upland and lowland surfaces in the Appalachian district have been interpreted as representing peneplains at two or more levels.[1] The interpretation of the preglacial history of the valley is beyond the scope of this article. The writer wishes to get before the reader a general picture of the region only, without reference to the preglacial history. (See Figs. 10 and 11).

In the Appalachian part of the Hudson the drift phenomena may be described in seven sections: (1) the Fishkill-Dutchess Junction Fig. 9, Nos. 42, 41), and Newburg-New Windsor deposits (38, 37); (2) high-level terrace north of Fishkill south of 44 and north of 42; (3) deposits from Carthage Landing to Lowpoint on the east side of the Hudson and at Roseton on the west side (Nos. 44 and 39); (4) New Hamburg gravel plateau and stratified drift on Wappinger Creek (Nos. 46 and 47); (5) Camelot kames (No. 48); (6) deposits north of Camelot from Poughkeepsie to Catskill; (7) deposits from north of Catskill to north of Glens Falls (Fig. 13).

The deposits in Division 1 are similar in import to those in Division 7, and are very much like the phenomena at Haverstraw and Croton.

[1] See R. D. SALISBURY, *Physical Geography of New Jersey*, pp. 8–14, 83–85, 94–98; BAILEY WILLIS, "Northern Appalachians," *National Geographical Society Monographs*, Vol. I; C. W. HAYES, "Southern Appalachian," *ibid.*, and W. M. DAVIS, *Proceedings of the Boston Society of Natural History*, Vol. XXV (1891), pp. 318 *et seq.*

The phenomena in Division 2 are somewhat like those from south of Peekskill toward Oscawanna, and indicate the presence of the ice in the valley near the north edge of the terrace when the deposits found here were being made. The Carthage Landing-Lowpoint and Roseton deposits indicate the presence of the ice in the valley when adjacent stratified drift at higher levels was accumulating. The New Hamburg gravel plateau and Wappinger Creek stratified drift indicate the presence of the ice in the valley at the edge of the New Hamburg plateau while the ice in the higher lands was retreating through the Wappinger Creek Valley.

I. NEWBURG-NEW WINDSOR AND FISHKILL-DUTCHESS JUNCTION.

These places are situated on opposite sides of the river. On each side the Haverstraw phenomena are repeated. Gravel plateaus underlain by clay are situated next to the river, and morainic phenomena occur on the higher land away from the river. The gravel plateau at Newburg is more delta-like in form than either at Haverstraw or Fishkill-Dutchess Junction. (See Fig. 12.) In the latter places the surface is marked by undulations similar in kind to, but more subdued than, those in the moraines on the adjacent higher land. Masses of till are found at Dutchess Junction in the clay, and ripple marks are found in the clay at New Windsor. (See Fig. 3.)

Interpretation: The interpretation of these deposits is similar to that of the Haverstraw deposits. It is difficult to see how the ice of a single ice-lobe can retire from a valley both to the eastward and to the westward, either simultaneously or successively, unless it be by the making of an embayment in its front. The evidence here, like that at Croton Point and Haverstraw, points to an embayment of the ice-front with at least wings of ice extending farther down the Hudson on each side. If the interpretation of the Jones Point, Roye Hook, and West Point-Cold Spring phenomena be correct, it would seem that the front changed from a protruding tongue in the Highlands and immediately south, to an embayment at Newburg—New Windsor and Dutchess Junction—Fishkill. This is similar to the interpretation of a protruding ice tongue south of Croton Point and Haverstraw and an embayment at those places.

The level to which the waters of the Hudson water body reached

seems to be 140 feet. It may have reached somewhat higher. The only means of determining this limit seems to be the maximum limit of the delta structure. The presence of kames or moraine does not fix an upper limit to the water, as indicated by the North Haverstraw kame-like bodies, at low levels and by kames at Camelot and other places to be mentioned hereafter.

Low-level terraces on the Fishkill and Quassaic have the same import as those at Croton. It is a question how much erosion has taken place in the Hudson Valley itself. If the ice was on the valley sides and the waters discharging into the valley which was free from ice, it would be expected that the valley would be filled entirely across up to the level required by the slope of the deposits from each side. Since the clay would naturally take a very gentle slope if the valley was free, it would be expected to fill to a height somewhat less than the height of the clay on each side, but not very much less. Altogether it seems probable that the erosion here has been more than 100 feet, while in regions immediately north it is very much less than this.

II. HIGH-LEVEL TERRACE NORTH OF FISHKILL.

One and one-quarter miles north of Fishkill a sand-and-gravel-capped clay terrace at 100 feet at its outer edge and 120 feet at its inner edge extends northward for about one mile, with a width of less than one-quarter of a mile up to three-quarters of a mile. The overlying gravel and sand have a depth of 6–10 feet, and the layers dip south. Near its north end gravel and sand occur at a higher level, with a slightly undulatory topography, which may mark the ice-edge on the land when the terrace was building in the Hudson water body. (See Fig. 9 south of No. 44 and north of 42.)

III. CARTHAGE LANDING-LOWPOINT AND ROSETON.

At the northwest margin of the above-mentioned 100–120-foot terrace a lower terrace of gravel-capped clay occurs at 20–40 feet A. T. The clay in this terrace varies in elevation from sea-level or below to 40 feet above sea-level. The gravel above the clay is coarse and contains some sink-like depressions. (Fig. 5, *C*.) It extends from a point one and one-quarter miles south of Carthage Land-

ing to a point three-quarters of a mile north of that place. For a half mile at its southern end it borders the undulatory gravel area mentioned above in connection with the 100–120-foot terrace. Nearer its north end it is separated from a higher deposit of sand-capped clay by a till area which has a slightly undulatory topography. (Fig. 5, *D*.) Opposite this low terrace, at Roseton and north toward Danskammer Light, a gravel-capped clay deposit occurs at a slightly higher level, with a terrace form. There are two hypotheses to explain these relations: (1) The deposits at Roseton once extended entirely across the valley and have since been eroded, and the 20–40-foot terrace is the product of erosion of the higher deposits. (2) The second hypothesis is that the Roseton gravel-capped clay terrace and the high-level clay deposit on the east side of the Hudson were never continuous, but that the ice occupied the valley when they were made, and stood on the 20–40-foot gravel terrace, but failed to build it as high as the 100–120-foot terrace to the south, or the Roseton terrace to the west and the clay to the east. The sinks in the 20–40-foot terrace, and the faint undulations in the till on he slope between the 20–40-foot terrace and the higher clay, bear this out. If this is the correct interpretation, it is a case similar in kind to the kame-like knolls near the North Haverstraw gravel plateau, and also like the phenomena just south of Peekskill near Verplancks. Under this interpretation the 20–40-foot terrace may or may not once have extended entirely across the valley. Under the first hypothesis both the high-level and the low-level terraces formerly extended entirely across the valley. It may be objected to the second hypothesis that when the ice had retired to New Hamburg, and the clays and sands and gravels were accumulating, some of the finer materials at least should have been carried south into this unoccupied part of the valley. This argument would be especially strong if the Hudson water body was subject to tides whose ebb would tend to carry the fine detritus down into this space. It is, however, not at all necessary to believe that the valley between these two terraces was unoccupied at this time. If the valley was occupied, it was by a mass of stagnant ice. There is evidence elsewhere that such masses of stagnant ice were left in the valley.

IV. NEW HAMBURG GRAVEL PLATEAU AND WAPPINGER CREEK STRATIFIED DRIFT.

A gravel plateau occurs at New Hamburg (46), which has a width in a north-south direction of about one-half mile, and connects with stratified drift which extends upstream to the northeast four miles or more, and spreads out to broader dimensions. It has an elevation at its west edge of 100 feet A. T., and a plain surface which rises upstream; and at Wappinger Falls (47), at an elevation of 140 feet A. T., it has a topography which indicates the presence of ice. Farther northeast kames occur in small areas. The edge of this plateau is steep at the northwest side, but farther south, and east of New Hamburg village, it falls off in undulations, which indicate the presence of the ice during its formation. Exposures in this plateau in this lower portion show layers of gravel and sand which dips west in the western part, and east in the lower portion of the eastern part. Apparently this gravel and sand grades into clay farther east. It will be noted that this would be upstream as the Wappinger Creek now flows. The easterly dipping layers are interpreted as the fore-set beds (of Davis) and the clay as the bottom-set beds. The westerly dipping layers are interpreted as the back-set beds. Farther upstream, just east of the Print mills, near the point where the surface topography indicates the co-operation of the ice in forming the plateau, gravel and sand in considerable thickness overlie silt and yellow clay which reach 60 feet A. T. or more. Blue clay was observed farther south on the left bank of the creek. The layers of gravel and sand dip west and southwest.

Low-level terraces: In the village of Wappinger Falls a lower terrace at 40–60 feet is to be seen, and also one at 20 feet. Both are made of gravel 2–3 inches in diameter. Farther downstream a terrace occurs at 30 feet A. T.

V. CAMELOT KAMES.

Near Camelot kames unassociated with the gravel plateau occur in a valley tributary to the Hudson within 20–40 feet of sea-level, and in the immediate Hudson Valley within 60 feet of sea-level. (Fig. 9, No. 48.)

VI. NORTH OF CAMELOT TO NORTH OF CATSKILL.[1]

From north of Camelot to Catskill the study of the deposits was made largely in passage, so that the relations of the deposits to the successive positions of the ice-edge cannot be stated. These fugitive observations indicate a general higher altitude of the deposits next to the valley side and a lower altitude next to the Hudson. They also indicate an alternate increase and decrease in the elevation both in the present Hudson bluffs and farther back from the river, and this is interpreted as indicating more than one stand of ice in this area. South of Poughkeepsie there is a pitted plain at 140 feet A. T. with a steep descent toward the Hudson, the origin of which is unknown. Gravel was observed at various points along the West Shore Railroad from West Park to Ulster Park, at elevations of 100 and 140 feet A. T. Clay was observed nearer South Rondout at 140 feet, and in South Rondout clay underlies sand which has an elevation of 150 feet. At Kingston along the Hudson a sand-capped clay terrace occurs 220 feet A. T., while farther west along the West Shore Railroad a plain at 180–200 feet A. T. is coated with sand and gravel that are said to be underlain by clay.

North of Kingston the clay has an elevation of 100–140 feet in the Hudson bluffs, and a higher elevation west of the bluffs, where sand covers the surface. At Glasco the clay has an elevation of 140 feet in the river bluffs and 180 feet along the West Shore Railroad two and one-half miles to the westward. At Saugerties and north toward West Camp it has an elevation of 140–160 feet. At Catskill it has an elevation of 100–120 feet, and a plain surface which has been trenched by the Catskill and its tributaries. It has been described here by Professor W. M. Davis, who has also described the delta of the Catskill.[2]

VII. NORTH OF CATSKILL TO NORTH OF GLENS FALLS.

Old lake-floor or old sea-floor.—In the Appalachian Valley part of the Hudson north of Catskill, and perhaps from north of Poughkeepsie the first approximation to a correct picture of the topography

[1] For places mentioned in this division see Fig. 1.

[2] *Proceedings of the Boston Society of Natural History*, Vol. XXV (1891), pp. 318–35.

is that of a plain descending gradually from the valley sides to the bluffs (of clay generally) bordering the present Hudson. The elevation, on the whole, increases from the south, where it is 100 or 120 feet to 180 feet, toward the north, where it is 220–240 feet along the bluffs of the present Hudson. From these elevations marking the bottom of the trough or the meeting of the slopes of the sea- or lake-floor, the plain rises eastward and westward to the higher land marking its limits. (See Fig. 14.)

Gravel plateaus and deltas.—Above the plain on the east and on the west rise gravel plateaus, some of them delta-like in form, which represent approximately the level of the waters when the floor above described was being built up. These gravel plateaus and deltas are found at the following places: On the left bank—(1) South Schodack and northwest at 340–360 feet; (2) Troy, 300 and 360 feet (?); (3) Hoosick River, 360 and 280–300*[1] (?) feet; (4) Batten Kill, 380–400 (?) and 300 feet; (5) At Glens Falls and vicinity, 460 (?), 389, 340*, and 280–300* feet. On the right bank—(1) South Bethlehem, at 300, 240*, and 200–220* feet; (2) at Maltaville, 340–360 feet; (3) at Saratoga and vicinity, 400 (?), 320–340, 300, and 260 feet; (4) southwest of Glens Falls, 340* and 380 feet—a continuation of the Glens Falls levels of the left bank.

The plateaus descend abruptly toward the plain. The layers of coarse gravel and sand of which they are generally made may sometimes be seen to dip at high angles in the same direction and to grade down the dip into the fine materials, and into the clay which makes up a large part of the plain. They are like those of Class 2 of the lower Hudson. The height of the gravel plateaus above the level of the floor varies from 160 to 180 feet on the north to 100–120 or 140 feet in the southern part of this area. While these gravel plateaus descend abruptly toward the old lake- or old sea-floor, and the stratification bears the significant relation to the clay plain mentioned above, the relation of the gravel plateaus up the slope of their surface is just as significant. When traced back they are found to connect,

[1] The stars indicate secondary deltas. Perhaps the 300-foot Troy delta should be considered secondary. Perhaps a part of the 300-foot delta on the Batten Kill is not secondary. It has been seen only in its northern part. Its southern part as represented on Fig. 13, No. 91 is hypothetical.

(1) with valley trains leading down from positions marking the ice-edge during its retreat: or (2) they head directly in kames or other morainic developments which are just as significant in showing the relation of the gravel plateaus to the source from which the material was derived, and from which emanated the waters that transported the delta materials to their present resting place. These kames and moraines have been traced back from the immediate Hudson Valley in a few cases, and have been seen to develop into fairly well-defined morainic topography, while in the lower lands the morainic phenomena are more subdued. Such kames and moraines are found at the following places: (1) At the eastern and northeastern margin of the South Schodack gravel plateau. The East Greenbush kame area makes a part of this belt. (See Fig. 13, Nos. 73, 74.) (2) The Teller hill kames (No. 75), which are fronted by clay without an intervening gravel plateau. (3) The line of kames and moraine extending from North Albany to Newtonville (No. 65.) (4) Kames at Troy (No. 76). (5) Glen Lake-Hopkins Pond kame belt north of Glens Falls (Fig. 18, Nos. 87 and 89. (6) Kames between New Scotland and Voorheesville (Fig. 13, Nos. 63 and 64.) (7) Kames at Saratoga Springs (Fig. 13, No. 84.) (8) The Moreau Pond belt of kames (No. 85.) That the relation of this kame belt to the gravel pla eau east of it is similar to the relation of the kames and gravel plateaus mentioned above, is not certain.

The surface of the gravel plateaus is sometimes marked by ridges or by deep sinks. The clay plain at the outer edge of some of these plateaus has a higher level than at the same edge of the plain farther north, or the reverse may be true. The clay plain sometimes fronts kame areas without an intervening gravel plateau, and the top of the kame area may be lower than the level of the gravel plateau immediately adjacent. On some of the streams, notably the Hoosick River, deltas occur without the undulatory surface. From north of the latitude of Mechanicsville to the northern part of Saratoga Springs, the western part of the lowland is occupied by a succession of gravel plateaus (area 50–75 square miles), with discordant levels which are separated by depressions having a general northeast-southwest direction, and in the bottom of which are lakes such as Round Lake, Saratoga Lake (with a length of 5–8 miles and a width of 2 miles),

and Lonely Lake. Probably Ballston Lake is thus situated. (See Fig. 13.)

Under several of these gravel plateaus, over wide areas, clay is reported. In the bottom of the Round Lake depression there is till, and a limited coarse gravel area with deep sinks in it, although clay and stratified drift rise in steep faces to the north and to the west, and perhaps in other directions. It is believed that these northeast-southwest depressions were occupied by masses of stagnant ice while subsequent plateaus to the northwest were being built, and that the northeast-southwest trend of the depressions indicate something of the direction of the ice-edge as it retreated. At Glens Falls[1] and north a succession of gravel plateaus is believed to mark the successive positions of the ice-edge in a similar way, but they are not separated by wide depressions, or depressions of any kind so generally. Below the level of these gravel plateaus are secondary deltas derived from higher gravels by erosion. It is believed that they have been recognized at South Bethlehem (two levels—one on Sprayt Kill and one on the Oniskethau) (Fig. 13, No. 62), on the Hoosick River (Fig. 13, No. 90), on the Batten Kill near Schuylerville (Fig, 13, No. 91), and on the Hudson in the vicinity of Glens Falls (two levels) (Fig. 18, Nos. 94 and 86.)

Elevations above old lake- or old sea-floor.—Above the plain in situations not confined to its borders there rises another class of elevations, some of which were islands in the sea or lake, when the gravel plateaus and deltas were being made. These hills sometimes are drift hills. More often they are drift-covered rock hills. Such islands may be seen in the following places:[2] (1) hill northeast of Saratoga; (2) highland east of Saratoga Lake; (3) hills north and south of Mohawk River; (4) hills southeast of Albany; (5) hills south of New Baltimore and at numerous places southward, where the elevations are ridges elongate in a north-south direction. Some of these hills may have formed shallows only, at the highest stage of the Hudson water body, but most of them were distinct islands and served to break the water body up into several more or less separate portions. There were doubtless other shallows or islands, and the elevations

[1] See also WARREN UPHAM, *American Geologist*, Vol. XXXII (1903), pp. 223–30.

[2] For these elevations see Fig. 13.

that made shallows at the highest stages of the water body must have produced islands and peninsulas at lower stages.

Depressions below old lake- or old sea-floor.—Below the level of the sea-floor or lake-floor plain there are two classes of depressions: (1) lake basins and similar depressions not occupied by lakes; (2) valleys produced by erosion. The depressions occupied by lakes are those like the Saratoga Lake basin and Round Lake basin, the origin of which has been referred to above and will be discussed below. The basins may be small—a few yards across and shallow; or they may be like the basin of Saratoga Lake, 5–8 miles in length and $\frac{1}{4}$–2 miles in width, and with a depth below the plain surface of 60–100 feet, plus the depth of the water in the lake.

The second class of depressions below the old lake- or old sea-floor are the valleys of the present streams, of which the Hudson is the chief. (Fig. 15.) Below Troy the Hudson is now an estuary, but above that place the tide does not reach. The course of the Hudson is interpreted as marking the trough of the depression down to which the old sea- or lake-floor sloped from each side, and which was followed by the main stream when the floor emerged from the waters in which it had been built. Some of the details in the course of the Hudson may be explained as due to the greater building out along one side of the lake or sea, as for example the westward bend of the Hudson opposite the mouth of the Hoosick River, where the building out of the delta from the eastern side of the valley crowded the depression farther out into the midst of the plain than to the north or to the south beyond the influence of the delta deposits. This westward bend amounts to about two miles. There is no doubt that similar explanations will account for the fact that the Hudson is nearer one side of the valley than the other in different portions of its course, and for other details; but it is probable that other slopes of the floor were the resultant of the interaction of several factors—the original topography of the valley, the rate of deposition by the agencies building up the floor, and the length of time the building continued. At any rate, the course of the Hudson may be considered a consequent course determined by the slopes of the old lake- or old sea-floor across which it flowed when the floor emerged from the lake or sea that had occupied it. Since that time it has trenched its course below the level of

the plain 150–170 feet north of Athens, 190–200 feet at Albany, and 80 feet near Fort Edward. This channel is now covered by tidewater to a depth varying from 10–25 feet at Albany to 15–50 feet north of Athens. This depth of water is included in the above estimates of erosion, from Albany south.

The tributaries of the Hudson have courses that are as significant as that of the main stream itself. The larger streams and the longer small streams that head in the country beyond the limits of the plain and above the level of the Hudson water body descend in general by rather steep slopes to the plain, cross the plain on gentle gradients and descend abruptly near their mouths to the Hudson (Fig. 16, *A*). On

FIG. 16.

A, profile characteristic of streams tributary to the upper Hudson, or flowing either into the Poultney-Mettawee or Fort Edward Valley; *B*, profile characteristic of streams crossing the clay plain and flowing into northern Lake Champlain.

the smaller streams in general this steep slope is not far from the Hudson, and on the larger streams in general it is less abrupt and is farther back from the Hudson. The courses of these streams like that of the Hudson have been determined with few exceptions by the topography of the old lake- or old sea-floor, and one may picture the streams as extending their courses across this floor following the slope of the land as the Hudson water body receded. To these consequent streams subsequent tributaries have no doubt been added, and to the original consequent character of the stream gradients has been added the steep gradient found at the mouth of so many of the streams. The full explanation of this will be taken up later, but it may be said here that this steep gradient is due to so rapid a cutting down of the valley of the Hudson that the smaller and weaker tributaries were unable to keep pace with it. The reason for this will appear later. In some cases the failure of the tributaries to keep pace with the Hudson in its downcutting is due partly to the disadvantage of a hard rock-bed, with which the Hudson did not have to contend.

SUBMERGED CHANNEL OF THE HUDSON.

The submerged channel extends from Troy, the limit reached by the tides, through the Narrows of Brooklyn and beyond out to the outer edge of the overwash plain fronting the Brooklyn moraine. Beyond this there are a number of channels, but none can be considered a continuation of the channel through the Narrows until opposite Sandy Hook, where a channel begins that can be traced southeastward to the forty-one-fathom line. (See Fig. 17.) Whether this should be considered a continuation of the Narrows channel will be discussed later.

Extra-morainic channel.—This channel can be traced from a point opposite Sandy Hook southeastward and ends at the forty-one-fathom line,[1] eighty nautical miles from Sandy Hook. In depth below the plain into which it is cut it varies from zero to 90 feet. Ten miles from Sandy Hook it has a depth of 48 feet, and increases south-eastward to 90 feet, and again decreases to zero feet, at the forty-one-fathom line. Beyond this channel, after an interval, there is a much deeper ravine, with which this paper is not concerned. It is 25 miles long, 3 miles wide, and has a maximum depth of 2844 feet.[2]

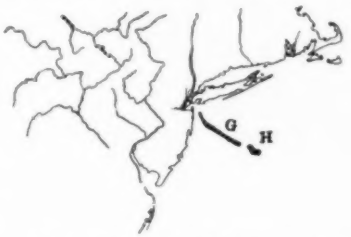

FIG. 17.—Submerged extra-morainic channel of the Hudson.

G, shallower channel to forty-one fathom line; *H*, deeper channel. [Taken from map by A. Lindenkohl in the *U. S. Coast and Geodetic Survey Report* for 1884.].

Channel inside the moraine.—The channel inside the moraine is covered by the waters of the Hudson estuary which vary from 10 to 216 feet in depth. On the whole, the minimum depth increases from Troy to just north of Newburg. South of here the water is shallow to the Highlands. In the Highlands it is deep, and from North Haverstraw south it is shallow again, but on the whole grows deeper to the Narrows. Throughout its entire length there is a very great variation in the depth, however. There are certain "deeps" which

[1] A. LINDENKOHL, *American Journal of Science*, Vol. CXXIX (1885), pp. 475–80.

[2] LINDENKOHL, *loc. cit.*

vary from a maximum of 216 feet at West Point to 120 feet and less. (See Fig. 8 for the submerged channels near New York city.)

WAVE-WROUGHT FEATURES IN THE HUDSON VALLEY.

There is an entire absence of wave-wrought features in the Hudson Valley, so far as known, with the possible exception of some gravel ridges on the low-level delta at Fort Edward east of Glens Falls, and some indistinct terraces on the west side of the valley south of Ballston.

BURIED SOILS.

An old soil with an elevation close to sea level has been observed on the clay surface south of Hackensack. It is overlain by ten feet of sand, the lower part of which contains clay a few inches in thickness, associated with fragments of leaves and woody stems. The soil is leached to a depth of one foot.[1]

On the east side of Newark Bay, south of the Lehigh Valley Railroad, a bed of peat or peaty soil is buried by 10–30 feet of sand, much and perhaps all of which is a wind deposit.[2]

FOSSILS IN THE HUDSON VALLEY, AND IN THE LOWLAND WEST OF THE PALISADE RIDGE.

The only fossils that have been found in deposits of the Hudson water body in the Hudson Valley are: (1) Sponge spicules, freshwater diatoms, and worm-tracks at Croton;[3] and (2) leaves of *Vaccinia oxycoccus* at Albany.[4] In the lowland west of the Palisade Ridge, near Hackensack, leaves and woody stems have been found in a bed of stratified sand and clay which underlies 8 feet of sand, containing a few gneiss bowlders, and overlies an old soil having an elevation close to sea level.[5]

[1] "Drift Phenomena of the Palisade Ridge," *Annual Report of the State Geologist of New Jersey* (1893), p. 207.

[2] *Loc. cit.*, p. 205, and GEORGE H. COOK, *Geology of New Jersey* (1868), p. 227.

[3] H. RIES, *Bulletin of N. Y. State Museum*, Vol. III, No. 12 (1895), pp. 119, 120.

[4] Described by Dr. James Eights in 1852 as probably *Mitchella repens*. Professor B. K. Emerson thinks they are probably *Vaccinia oxycoccus*, which are the most abundant leaves in the clays of the Connecticut. See *Monograph of U. S. Geological Survey*, Vol. XXIX, p. 718.

[5] "See Drift Phenomena of the Palisade Ridge," *Annual Report of State Geologist of New Jersey* (1893), p. 207.

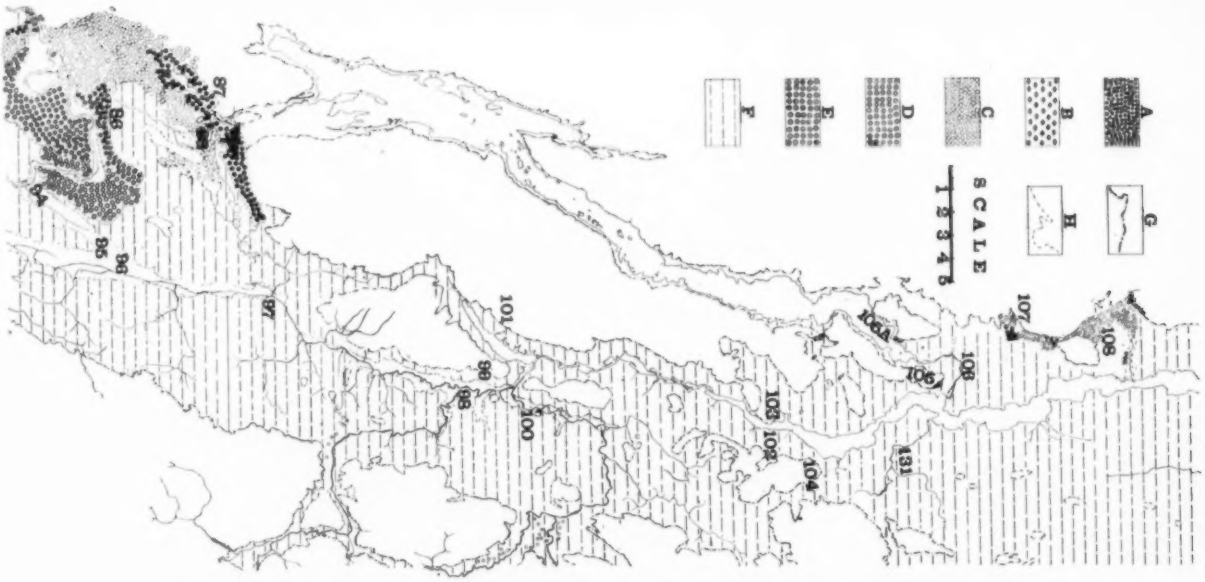

FIG. 18.—Showing known areas of stratified drift from south of Glens Falls to north of Crown Point.

LEGEND: *A*, moraines and kames, generally. In some places ice-shaped drift-forms that are neither moraine or kames are thus indicated. *B*, ice-molded stratified drift. *C*, gravel plateaus made by ice waters. *D* and *E*, secondary deltas. *F*, clay chiefly, but other forms of stratified drift are included. Knowledge is more certain where lines are not broken. *G*, approximate limits reached by the standing water. *H*, boundary lines showing approximate limits of the features inclosed. The white space next to the streams marks swamps, flood-plains, and low-level terraces. The heavier circles southeast of 107 and northeast of 108 show secondary deltas.

The numbers refer to the following places:

86, Glens Falls; 87, Glen Lake and Glen Brook; 88, Queensbury, Round Pond, and Jenkins Mills; 89, Hopkins Pond; 94, Fort Edward; 95, Dunham's Basin; 96, Wood Creek; 97, Fort Ann; 98, Mettawee River; 99, Whitehall; 100, Poultney River; 101, South Bay; 102, Benson Landing; 103, Putnam Station; 104, Addison-Rutland county line; 105, Mount Defiance; 105A, Baldwin; 106, Ticonderoga; 107, Street Road; 108, Crown Point Center; 131, East Creek.

WESTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

North of Glens Falls (where the Hudson emerges from the Adirondacks) the broad lowland occupied by the Hudson ends suddenly in the rather abrupt rise of the land caused by the closing in of the highlands from the east and from the west. Through this highland there are two narrow passages—one by way of Lake George, and the other by way of Whitehall and southern Lake Champlain. These two passages are separated by highlands reaching elevations of more than 2,000 feet, and with a common elevation of 1,200–1,800 feet. This highland ends, however, in Mount Defiance near Fort Ticonderoga, and north of this place the two passages unite and broaden out into the wide valley between the Adirondacks on the west and the Green Mountains on the east, in the bottom of which is Lake Champlain. (See Fig. 18.)

The Western or Lake George Passage is a long, steep-sided, narrow valley opening out on a clay plain near Ticonderoga at the north and connecting with the Lake Champlain valley. In the bottom of this valley is Lake George, 32 miles long, and 2 miles wide in its southern, and one-half as wide in its northern part. Its greatest depth is 110 feet. At the south end of this valley there are two gaps, the western one of which has a rock-bottom at more than 500 feet A. T. The eastern and broader gap is blocked by a massive complex gravel ridge, which is a northeastward continuation of the Glen Lake kame area. (Fig. 18, No. 87.) Well data to the south of this ridge indicate a filled valley with a bottom which is lower than the deepest known part of Lake George. Through this massive gravel ridge, which obstructs the south end of the Lake George valley and is responsible for Lake George, there is a small gap followed by a tributary of Glen Brook (the outlet of Glen Lake). This tributary appears from the map to flow through a flat-bottomed valley, and one of its branches starts from a low divide at 349 feet A. T. in this valley, which separates it from streams flowing into Lake George. As will be seen later, this flat-bottomed valley may have been the outlet for a higher glacial Lake George, which existed (if it existed at all) after the ice had retreated beyond the Glen Lake kames and before it had retreated north of Ticonderoga. (See Fig. 18, No. 106.)

EASTERN PASSAGE FROM HUDSON TO CHAMPLAIN VALLEY.

East of the highland through which is the Lake George passage the lowland of the Hudson valley is continued to Lake Champlain with a width of 5–6½ miles. The higher hilltops in this lowland are 300–400 feet below the highland farther east, and are more than double this amount below the western highland. The lower hills in the lowland have elevations of 200–400 feet lower than the higher and reach elevations of 300–520 feet.

The clay and stratified drift found in the Hudson Valley is likewise found through this lowland connecting the Hudson and Champlain Valleys. South of the Addison-Rutland county line and east of Lake Champlain it is somewhat discontinuous because of the numerous hills rising above the levels reached by the waters in which the clay accumulated. In the lower lands along the narrow part of Southern Champlain it probably was once continuous. Cut into this old clay-floor there is a valley which extends from the Hudson northward. It has two divisions which will be called the Fort Edward Valley and the Whitehall-Putnam Station Valley. These will be described presently. (See Fig. 18, Nos. 94, 99, 103.)

CHAMPLAIN VALLEY.

The lowland of the eastern passage above described extends into the Lake Champlain region, where it is found between the Adirondacks on the west and the Green Mountains on the east. It is made of the softer sedimentary rocks generally, over which are the clays and other classes of drift corresponding to those found in the Hudson Valley.

EAST SIDE OF LAKE CHAMPLAIN.

North of the Rutland county line the more hilly higher land recedes eastward from the lake shore, and from the descriptions of Baldwin[1] and some observations of the writer it would seem correct to state that the lower land near the lake is marked by a wide clay-mantled plain as far north as the Winooski, where gravel and sand deposits interrupt. It occurs again north of the gravel and sand plains of the Missisquoi River. To the eastward the clay decreases in quantity or ceases altogether, and on the higher land the drift-covered or bare rock hills cease to be mantled with the clay.

[1] *American Geologist*, Vol. XIII (1894), pp. 170–84.

Through the clay on the plain high hills rise to levels beyond that reached by the waters in which the clay accumulated. These hills are drift-covered, and the rock outcrops frequently. Other lower hills, which sometimes have the form of ridges, have rock cores, are till-covered, and are mantled by the clay so as to subdue the original irregularities of the rock and drift.

WEST SIDE OF LAKE CHAMPLAIN.

While this plain has its widest extent in the southern Champlain Valley on the east side of the lake, it has been most studied on the west side. From Ticonderoga to Port Kent the plain is not more than 3 miles wide at any point, and contracts and expands as the mountains approach or recede from the lake shore. The mountains approach close to the shore just south of Crown Point, both north and south of Port Henry, south of Whallonsburg, and north of Willsboro. They recede from the shore, near Ticonderoga, at Crown Point, from a few miles north of Port Henry, to Westport, and again from several miles south of Willsboro to a few miles north of that place. North of Port Kent the plain widens out continually to the national boundary. In its lower eastern part clay prevails at the surface, except along the streams. In the higher western part till frequently covers the surface. (See Figs. 18 and 1 for places mentioned.)

Gravel plateaus and deltas—upper and lower series.—On approach to the higher land the plain ends abruptly against the drift-covered slopes or in gravel plateaus analogous to those in the Hudson Valley. Near the rivers the plain gives place to a series of deltas and gravel ridges, which are grouped into two series—an upper and a lower, with a space of about 120 feet between the series. The upper series has a range of about 80–100 feet at the north and a greater range at the south. These gravel plateaus and deltas are, on the whole, higher at the north than at the south, but there are exceptions. Their elevations are as follows: Street Road gravel plateau, 540; delta, 320–340. Delta on Bouquet River, 460–480; 400 (?). North Branch Bouquet River near Tower's Forge, 460–80; 400 (?); near Reber, 440–60. Ausable River, 580–600 (?); 500. Saranac River, 640 (?); 520–40. The top of the Street Road 540-foot plateau may be higher than the level reached by the standing water. The lower series

of levels is made up of a succession of deltas and bar-like gravel ridges, and has a range from about 180 to 200 feet A. T. at the south, and 420 to 450 feet A. T. at the north, down to the level of Lake Champlain (101 feet above sea-level). The upper series of deltas consists of two—an upper and a lower. The upper one was made by the ice waters. The lower was made by the erosion of higher gravels. The one made in the presence of the ice may be absent on some of the more northerly streams.

Wave-wrought terraces.—Corresponding to these two series of gravel plateaus or deltas there are two series of wave-wrought terraces separated by an interval of about 120 feet at the south and 155 feet at the north. In this interval the terraces are either absent or very faint.

Upper series of wave-wrought terraces: The upper series of terraces have been seen at various points from Street Road to West Chazy. They have not been studied north of the latter place. This series of terraces has a range at Street Road and Crown Point of 200–220 feet (520–320 feet A. T.), if certain rather faint terraces be accepted as wave-wrought. The range of terraces at the north varies from 75 feet near Whallonsburg (510 –435 feet A. T.) to 80 and 100 feet farther north. On the whole the range increases northward from Whallonsburg, but is still greater at Street Road and Crown Point. Except for the fact that the upper terrace at Whallonsburg and corresponding deltas on both branches of the Bouquet River are somewhat lower than at Street Road or Crown Point, the series increases in altitude northward. Both series of terraces are best developed and have been studied most at places from Port Kent northward.

In this region the upper series of wave-wrought features is distinct, and, when one's attention has been called to it, is somewhat conspicuous. The series embraces wave-cut terraces and gravel beach ridges, and in favorable situations bars, spits, and hooks. At places where these features can best be seen they have a range of (1) about 80 feet at Port Kent; (2) 80–90 feet one-half mile west of Harkness Station; (3) 77 feet east of Mount Ætna and a little north, between the latitude of Peru and Schuyler's Falls; (4) 60 feet northwest of Peru a few miles, and nearer Schuyler's Falls than (3) above; (5) south of the Saranac River on the farm of Thomas Riley and a neighbor, the

range is 100 feet and possibly somewhat greater; (6) southwest of West Beekmantown one and one-half to two miles the range is 80 feet (600–680 feet A. T.); (7) three to three and a half miles north of the latter place, and about the same distance southwest of West Chazy, the range is 95 feet (605–700 feet A. T.). The lowest terrace of this series when projected southward connects with the bottom of the Fort Edward Valley.

Lower series of wave-wrought terraces: A gap intervenes between the lower terrace of the upper series and the upper terrace of the lower series, in which the signs of wave-action are either very faint or altogether lacking. Because the lower series of terraces is often fainter, there is some uncertainty as to the amount of this gap. At Street Road it seems to be about 120 feet; at Crown Point 100–120, and possibly 140 feet. At Port Kent this gap is 124 feet (380–504 feet A. T.). At the Saranac River it is not known exactly. It is as much as 120 and no more than 165 feet. West of West Chazy it is 155 feet. The upper part of this lower series of terraces has been examined at a few points only; namely, west of West Chazy, where distinct terraces and beach ridges range from 450 down to 400 or 380 feet A. T. Other lower levels not systematically studied are to be seen east of West Chazy. At Port Kent an extensive series of terraces and beach ridges and bars was observed to extend from an elevation of 380 feet well down toward present Lake Champlain level. There were at least thirteen levels represented. The terraces of the lower series are best brought out along the streams. They have been observed on the south side of the Saranac, where sixteen levels were observed between an elevation of 300 feet and the level of Lake Champlain. They also occur on the Salmon River. At some of these levels, low-level deltas were built. Between Port Henry and Westport the low-level terraces may be represented at several places. At Crown Point a delta level appears to be present at 180–200 feet A. T., and indistinct terraces below this level have been seen south of Crown Point.

At Street Road distinct terraces occur at 160–180 feet, and indistinct terraces are perhaps represented up to 220 feet A. T. The upper terrace of this series projected southward falls below the Fort Edward valley.

Fossils.—Below the upper terrace of the lower series of terraces marine fossils occur on the west side of Lake Champlain at the following elevations: Plattsburg, 346 feet A. T.;[1] Port Douglas, 300 feet A. T.; Willsboro, 200 feet A. T.; Port Henry, 140 feet A. T. So far as the writer knows, the last-mentioned place is the most southerly point where marine fossils have actually been found.

At South Plattsburg both marine shells and vegetation are found in a deposit of sand and silt, the top of which has an elevation of 220 feet.

SALMON RIVER SECTION, NEAR SOUTH PLATTSBURG.[2]

15. Silt.
14. Ten feet of coarse gravel, with ridge topography. The sand below the gravel ridges is eroded and replaced by coarse gravel, largely of Potsdam sandstone, but some light-colored limestone. Shells in single valves. One square-shouldered valve found.
13. Six feet of sand (and gravel?), some stratified; single valves of round-shouldered shells.
12. Fifteen to twelve feet of sand and silt with round shouldered-shells in the sand.
11. Eight feet of coarse sand; shells rare—only one found.
10. Two feet of fine sand, a three-inch layer with occasional round-shouldered shells (valves together).
9. Clay and sand; a four-inch log, two inches from the bottom of the layer; shells rare.
8. Shells and vegetation.
7. Two feet two inches of alternating sand and clay.
6. Layer of vegetation one-half an inch thick, with a fragment of a beetle.
5. One foot of sand.
4. Two feet nine inches of sandy clay; no shells, but vegetation marks.
3. Blue clay; square-shouldered shells in sandy seam with specks of vegetation four feet above the river.
2. Till; stony material, largely limestone; some purple quartzite.
1. Rock.

The layers of sand and silt are much contorted near the surface, and again not far from the base of the section. The dip is eastward at a low angle. Just a little farther downstream there are several

[1] DR. D. S. KELLOGG, *Science*, June 17, 1892, p. 341.

[2] The material found in this section has not been fully identified but is being studied. Leaves in layer 6 have been identified by Professor J. M. Coulter as belonging to some species of boreal willow. The square-shouldered shells are probably *Saxacara rugosa* and the round-shouldered shells are *Tellina Groenlandica*.

different levels of the gravel with the form of limited terraces, which are due to the slumping down of the surface as the bank has been undercut. A layer of sand containing marine shell fragments and colored by the presence of vegetation was observed west of Mooers. It underlies coarser gravel and sand. The exposure was not sufficient to allow it to be determined whether the sand with the carbonaceous material represents an old soil or is a layer like some in the Salmon River section, colored with vegetable matter.

On the east side of the lake.—Marine shells in the form of *Macoma fusca* and *Saxicava* occur at low levels. North of central Addison Township Baldwin says they are common at levels below 150 feet, and reach an elevation close to 250 feet at Vergennes. The writer was unable, however, to find any up to that level south of Otter Creek at Vergennes, and search was not made north of that place. Baldwin also reports *Macoma fusca* at Shelburne Falls and Morses in stratified sands up to 180 feet. In the northern part of Shelburne shells which from descriptions are thought to be marine are reported, he says, at 400 feet. If this is correct, it is the highest level at which they have been found. The same writer reports shells of *Saxicava* and *Macoma fusca* in the stratified sands of the 270-foot LaMoille delta at Checkerberry village, on the south shore of Mallett's Bay and in West Milton.

Bones of a whale (*Beluga Vermontana*, Thompson) were reported from Charlotte Township at 150 feet above the sea.[1] Land-snail shells have been found in high-level deposits at a number of points in the southern Champlain region a few feet beneath the surface. In one or two cases they appeared to be imbedded in the undisturbed stratified materials of wave-wrought terraces. In most cases they occur in a surface loam which has a very irregular contact with the underlying drift. A number of things connected with their occurrence in the loam point to introduction in openings made by roots of trees, but it is possible that some were buried contemporaneously with the making of the wave-wrought terraces of the upper series.

Moraines.—Above the upper series of terraces at a number of

[1] *Vermont Geological Survey*, Report in 1849, Vol. I, pp. 162–65; and DAWSON, "Cetacean Remains in Champlain Deposits," *American Journal of Science*, Vol. CXXV (1883), pp. 200–202.

points, notably (1) at Crown Point, (2) between the latitude of Harkness and the Salmon River, and (3) at Cadyville and westward toward Dannemorra, a moraine or a series of moraines with a peculiar ridge-like topography have been observed on the eastern mountain slope. At two places these moraines are situated across the course of streams in the valleys of which gravel plains occur on the upstream side of the morainic ridges, reaching to the level of their lowest part. The situation is such as to suggest the presence of local lakes in which the gravel was deposited. This point is mentioned here to call attention to the fact that the ice at this stage, at any rate, and in this part of its front, did not have the same relation to the gravel plateaus as in the upper Hudson, for apparently its edge was on the landward side and the body of ice was on the lakeward side. This appears to have been true when the Street Road gravel terrace was made, but where the ice-edge and the body of ice were at Crown Point when the highest deposits of lacustrine origin were deposited is not known. It seems difficult to reconcile the stratified drift, with its eastward-dipping layers, with the position of the ice when the moraine higher up on the mountain side was made. The deltas on the Bouquet River are so situated that it is not necessary to assume either an embayment in the ice-front or a protruding tongue of ice down the Champlain Valley. The possible 580-foot Ausable "delta" may be interpreted with either front. The Saranac high-level delta indicates the presence of the ice at its northern margin, and possibly also at its western margin; but this delta, if it be a delta, is not well known.

Below the level of the lowest terrace of the upper series a group of kames which may mark a position of the ice-edge was seen northwest of Peru, and morainic topography was likewise observed one and three-fourths to two miles west of West Chazy, between the upper and lower series of terraces.

Eskers.—An esker with a length of eight to ten miles, and with a north-by-west and south-by-east direction, is found north of the latitude of Beekmantown,[1] and a mile and a half northwest of Treadwell Bay. Its top has a maximum elevation of 240 feet and a com-

[1]This esker was first described by DR. D. S. KELLOGG, of Plattsburg. See *Science*, June 17, 1892, p. 341.

mon elevation of 220 feet. It stands 20–40 feet above its surroundings. The top is often quite flat and has been subjected to considerable wave-action. The materials are frequently coarse gravel, with occasional large bowlders. A number of wells on this esker are reported by their owners to reach clay after penetrating the gravel. Marine shells are found on the slopes of this esker a few feet beneath the surface.

The streams and their valleys.—Down the slopes of the higher land the streams extended their courses as the waters of the lake, and subsequently the waters of the sea withdrew and exposed more and more of the lake-floor and sea-floor. The courses which the streams took were determined by the slope of the land. Into their deltas the streams have cut valleys, and some have cut, not only through the delta gravels, but also through the underlying till and into the rock below. This is notably true of the Ausable River, which has reached the Potsdam sandstone at a number of places from above Keeseville to Ausable chasm. At the latter place it has cut into the Potsdam rock to a depth of 80–100 feet, causing the falls to recede from their original position at the lower end of the chasm to their present position one and an eighth miles back. The Saranac River has not only cut through the morainic ridge west of Cadyville, but through the till and into the underlying Potsdam sandstone; again to the eastward it has cut through the upper delta deposits and underlying till into the underlying sandstone. The Saranac from Cadyville downstream some distance, and the Ausable from the lower end of the chasm to some distance above, have remarkably crooked courses, with almost rectangular turns, which have been determined by the joint planes of the rock. (See Fig. 19.)

Successive stages in the downcutting of their valley-fillings are shown by a series of river terraces on the Ausable above and below Keeseville, on the Salmon River above South Plattsburg, on the Saranac above Morrisonville; and doubtless on many other streams. The successive levels of the waters of the lake and of the sea are shown on the streams by lower deltas and by lower bars and beach ridges. Some of these low-level deltas are not simple, but appear to contain glacial deposits buried in and modified by subsequent deposits. This is notably true on the Ausable.

In the southern Champlain Valley the tributaries bear evidence of recent drowning of their lower courses. North-heading streams show a recent revival, while south-heading streams show *arrested development.*

In the eastern passage to the Hudson a valley has been mentioned which will be described in two divisions as the Fort Edward Valley

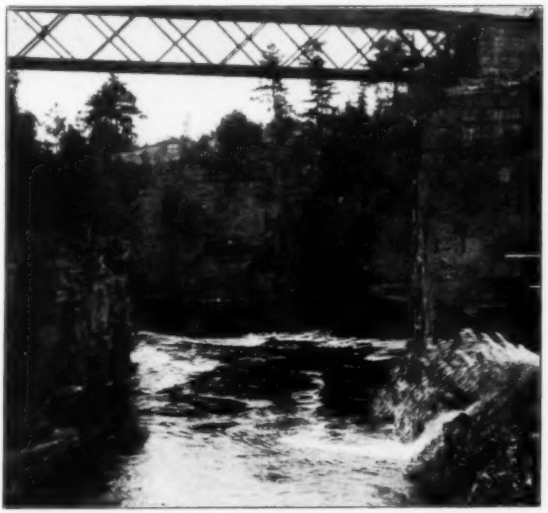

FIG. 19.—Showing the relation of the joint structure in the Potsdam sandstone to one of the rectangular turns in the Saranac River.

[Photograph by W. S. McGee.]

and the Whitehall-Putnam Station Valley. The tributaries flowing into these valleys show characteristics similar to those of the Hudson tributaries. They descend to the main valley, over steep slopes, which have been pushed farther back on the larger streams and reduced to gentler slopes than on the smaller streams, except where the rock has been encountered. This character is to be contrasted with the comparatively gentle gradients of the streams flowing into Lake Champlain farther north, where the streams lack the sudden descent at their mouths that is characteristic of those flowing into southern Champlain or into the Fort Edward Valley, except where

such descents have been produced by inequalities in the hardness of their beds. (See Fig. 16, *A* and *B*.)

Fort Edward Valley.—This valley extends from the south end of Lake Champlain at Whitehall to the Hudson River. From Dunham's Basin south it is divided into two parts. The western part ends at Fort Edward. The eastern part ends three miles farther south, and about the same distance north of Fort Miller. The narrowest part of the valley is at the edge of the highlands north of Fort Ann, where the width is one-tenth to one-fifth of a mile and the bottom is on the rock. The widest part of the valley, where the width is more than one and a half miles, is southeast of Dunham's Basin. The combined width of the eastern and western parts in the latitude of Fort Edward is nearly two miles. The bottom of the valley has an elevation, at Fort Edward, of 140 feet, an altitude which is probably considerably less than twenty feet higher than the present Hudson. The same may be said of the eastern branch of the valley three miles north of Port Miller. At Whitehall the valley bottom is 120 feet in altitude above the sea. Between these two extremes the divide, which is near Dunham's Basin, is close to 160 feet in altitude. The valley is followed by the north-flowing Mettawee River and its tributary, Wood Creek, and by the south-flowing Fort Edward Creek and Durkeetown Creek, a tributary of the Moses Kill. All these streams are very small compared with the width of the valley.

The amount of cutting of the valley is difficult of exact determination. At Fort Edward it certainly is less than 120 feet, and perhaps no more than 35 feet. In other places, on the whole, the indications are that there has been a cutting of less than 100 feet. The maximum possible cutting of the Hudson valley immediately to the southward is 160 feet, but may be only 100–120 feet.

Whitehall-Putnam Station Valley.—This valley is occupied by the southernmost and narrowest portion of southern Lake Champlain. This part of the lake, including swampy borders, has a width varying from one-tenth to seven-tenths of a mile, and a common width of one-half mile. Its sides show frequent cliffs of clay, or clay overlying silt and stratified gravel and sand, and remnants of a former valley-filling which reached, in places at least, elevations of 180–200 feet A. T. Beneath the waters of this part of the lake, and extending

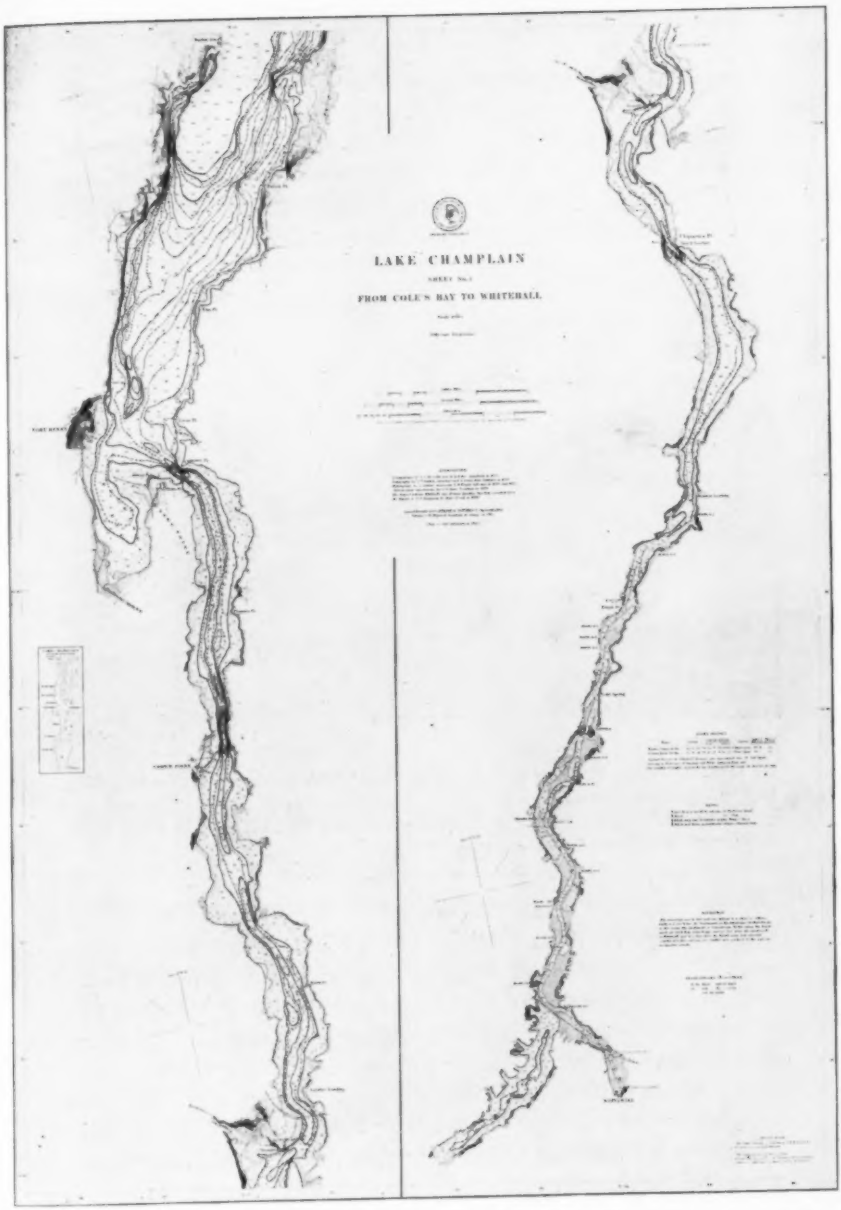

FIG. 20.—The submerged Poultney-Mettawee Valley, from Lake Survey Charts on which contour lines have been drawn. Contour interval: 5 feet, down to the ninety-foot line.

beyond it to a point five miles northeast of Port Henry, is the submerged Poultney-Mettawee Valley. (See Fig. 20.)

Submerged Poultney-Mettawee Valley.—This valley can be read from the Lake Survey charts. It occurs beneath the waters of southern Champlain from Whitehall to five miles northeast of Port Henry. The depth of water covering this valley varies from 12 to 55 feet

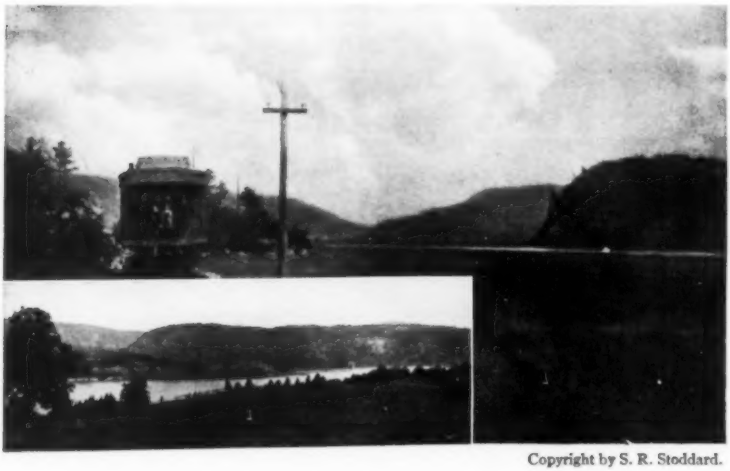

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FIG. 21.—Photograph of southern Lake Champlain, looking north near Dresden Station. Smaller view looks northwestward from Benson Landing across Lake Champlain toward Putnam Station. Beneath the waters of the lake in both views is the submerged Poultney-Mettawee Valley.

[Smaller photograph by W. S. Mc Gee.]

upstream from the delta. The outer edge of the latter is covered by water from 50 to 78 feet deep, depending on the interpretation of the edge. The depths of the valley are greatest at the narrowest parts, and the greatest depths are nearly as great at the south end of the valley as near the north end. South Bay seems to be a drowned valley partly filled, which was tributary to the main Poultney-Mettawee.

The width of the valley varies from one-tenth to one-half of a mile. Its sides are often steep, and the Lake Survey charts indicate plain areas between the cliffs which rise above the water of Lake Champlain and the tops of submerged bluffs. (See Figs. 20 and 21.)

Erosion of tributaries flowing into southern Lake Champlain.— From South Bay northward the tributaries from the west have cut valleys 40–60 feet deep below the top of the clay, and in a few cases near the lake shore as much as 60–80 feet deep. Between the valleys the points of land show cliffs furnishing numerous exposures along the Delaware and Hudson R. R. The streams on the east side of the lake are less numerous and flow down from land with a less elevation; in general, their valleys are not so extensive. Several show erosion to a depth of 40–60 feet, and perhaps one has cut as deep as 100 feet near its mouth. These figures refer to the depth of the valley above Lake Champlain level, and do not include depths below the lake-level. The lower parts of many of these tributary valleys are drowned for a distance of three-tenths of a mile from the cliff heads, and swampy bottoms farther up the valley in some cases occupy a probable former extension of the lake for five-tenths to seven-tenths of a mile.

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[*To be concluded.*]

Reviews.

The Non-Metallic Minerals. By G. P. Merrill, New York: John Wiley & Sons, 1904.

The non-metallic minerals, exclusive of gems, building-stones, and marbles, are treated in groups as elements, sulphides, oxides, etc. The nature and composition, the geological and geographical occurrence, the theories of the origin, and the uses of each mineral are presented, and in the case of the more important minerals commercially a brief description is given of the methods of mining and the preparation for the market. A valuable feature of the book to those who are making a study of special minerals is a bibliography giving complete references to articles and books on the various subjects. The occurrence of minerals, their forms of crystallization, and many other features are illustrated by numerous half-tones, diagrams, and geological sections. The author has rendered a most important service to all who are in any way interested in the non-metallic minerals by bringing together in a most concise manner much valuable information which until now was so widely scattered that it could be obtained only with great difficulty.

G. F. K.

Geology of Miller County. By Sydney H. Ball and A. F. Smith. With an Introduction by E. R. Buckley. Vol. I, Second Series. Jefferson City, Mo.: Missouri Bureau of Geology and Mines. 1903.

This is a report of 207 pages with 18 plates and sufficient figures to afford ample illustrations. Two maps accompany the report, the first one a geological map purely, and the second one an economic map showing locations of mines, quarries, clay-banks, etc. Many of the figures consist of detailed columnar sections of the different formations.

Miller county is located in the midst of the Ozark plateau, and the succession of formations is typical for most of the plateau region. The formations occurring in the county are the Proctor limestone, probably of Cambrian age; the Gunter sandstone, Gasconade limestone, Bolin Creek sandstone, St. Elizabeth formation, Jefferson City formation, and Pacific sandstone, of undifferentiated Cambro-Ordovician age; the undiffer-

entiated Jefferson City and Coal-Measure shale, Burlington limestone, Graydon sandstone, Saline Creek conglomerate, and coal and Coal-Measure shale, of Carboniferous age; and the alluvium, of Pleistocene age.

The field-work on the report under review was begun in November, 1901. At that time there were forty-nine counties for which reports and maps had never been issued; forty-nine counties for which general reconnoissance reports had been published; one for which a complete detailed report had been published; and twenty parts of counties for which detailed reports had been published. It is the purpose of the Survey to issue reports in detail upon the forty-nine counties for which no reports have been published, and under this scheme the report on Miller county is the first to appear, although the field-work has been done in two other counties. County reports are to be issued in preference to sheet reports, because it is the belief that they serve better the interests of the citizens of the state. It is the general plan of the Survey to extend the county surveys to the southwest, southeast, northeast, and northwest, thereby connecting with the surveys of the lead, zinc, and coal fields of the state.

In the *Geology of Miller County* all phases of the subject are discussed in considerable detail. In the chapter on the physiography of the region the different types of surface relief are first described, and the relations of physiographic types to industrial and social conditions are set forth in a brief but very interesting way. The major portion of the report is then taken up with careful descriptions of the different geological formations, dealing with their areal extent, thickness, bedding, weathering, composition, texture, relations to adjacent formations, porosity, color, fossils, topography, etc. A chapter is devoted to a discussion of structure, with folding and flexing, faulting, jointing, and unconformities as sub-headings. Another chapter deals with the origin of chert and dolomite. The final chapter is given over to economic considerations, and consists of descriptions of the manner of occurrence, origin, and other characteristics of barite, building-stone, clay, coal, iron, ore limestone, lead, and zinc, road materials, sand, silica, soils, etc.

The Geological Survey of Missouri has been in existence for a good many years and has issued some excellent reports. It has done a notable service to the people of the state, and to it also the geologists of the country are indebted. The volume just issued will be of great value to the citizens of Miller county, and will be well received by all persons without the county who are interested in geology. The report is written in such a way that it can be used in the public schools of the state, and is hence of direct educational value. It is so complete in its treatment of the subject that another

report upon the county will not be needed for many years. A topographic map would have increased the value of the report, and no doubt the reader without the state who is unfamiliar with Missouri geography (as is the case with the reviewer) would appreciate a small index map showing the exact location of Miller county. It is a source of regret that where the matter has been so well prepared the proof-reading should have been so carelessly done, and that the proportion of misspelled words should be so large as a necessary consequence.

H. L.